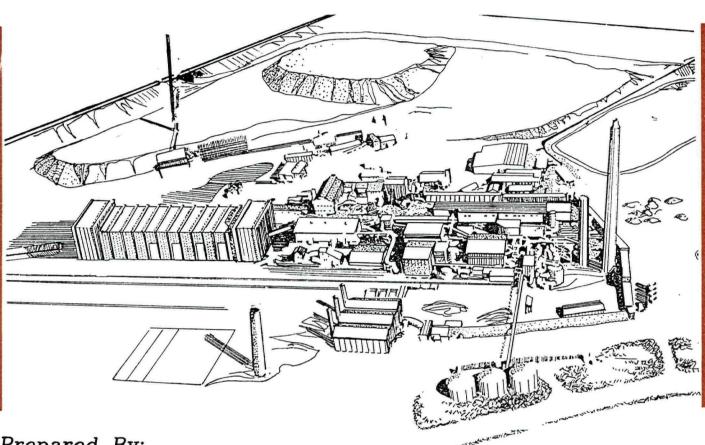


Volume 6

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Comprehensive Remedial Investigation/Feasibility Study - ASARCO, Inc. East Helena, Montana



Prepared By:

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Consulting Scientists and Engineers Helena, Montana

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APPENDIX 11-1-1

GROUNDWATER ISOLATION/CONTAINMENT PROCESS OPTIONS DESCRIPTION

APPENDIX 11-1-1

GROUNDWATER ISOLATION/CONTAINMENT PROCESS OPTION DESCRIPTION

GROUNDWATER WITHDRAWAL WELLS AND INJECTION WELLS

Groundwater pumping techniques involve the active manipulation and management of groundwater in order to contain or remove a plume or to adjust groundwater levels in order to prevent formation of a plume. Types of wells used in management of contaminated groundwater include wellpoints, suction wells, ejector wells, and deep wells. The selection of the appropriate well type depends upon the depth of contamination and the hydrologic and geologic characteristics of the aquifer.

Well systems are very versatile and can be used to contain, remove, divert, or prevent development of plumes under a variety of site conditions.

Pumping is most effective at sites where underlying aquifers have high intergranular hydraulic conductivity. It has been used with some effectiveness at sites with moderate hydraulic conductivities and where pollutant movement is occurring along fractured or jointed bedrock. In fractured bedrock, the fracture patterns must be traced in detail to ensure proper well placement.

Where plume containment or removal is the objective, either extraction wells or a combination of extraction and injection wells can be used.

Use of extraction wells alone is best suited to situations where contaminants are miscible and move readily with water; where the hydraulic gradient is steep and hydraulic conductivity high; and where quick removal is not necessary. Extraction wells are frequently used in combination with slurry walls to prevent groundwater from overtopping the wall and to minimize contact of the leachate with the wall in order to prevent wall degradation. Slurry walls also reduce the amount of contaminated water that requires removal, so that costs and pumping time are reduced.

A combination of extraction and injection wells is frequently used in containment or removal where the hydraulic gradient is relatively flat and hydraulic conductivities are only moderate. The function of the injection well is to direct contaminants to the extraction wells. This method has been used with some success for plumes which are not miscible with water. One problem with extraction/injection well systems are dead spots (i.e., areas where water movement is very slow or nonexistent) can occur when these configurations are used. The size of the dead spot is directly related to the amount of overlap between adjacent radii of influence; the greater the overlaps the smaller the dead spots will be. Another problem is that injection wells can suffer from many operational problems, including air locks and the need for frequent maintenance and well rehabilitation.

INTERCEPTION AND INFILTRATION TRENCHES

Interception trenches can be excavated to control groundwater gradient and collect contaminated waters for containment or treatment.

Application is best suited for low permeability unconsolidated materials.

Infiltration trenches can be used in much the same way as infiltration wells. Gradient can be controlled in combination with interception trenches. Infiltration trenches also are potentially useful for disposal of treated waters.

SLURRY WALLS

Slurry walls are the most common subsurface barriers because they are a relatively inexpensive means of vastly reducing groundwater flow in unconsolidated earth materials. The term slurry wall can be applied to a variety of barriers all having one thing in common: they are all constructed in a vertical trench that is excavated under a slurry. This slurry, usually a mixture of bentonite and water, acts essentially like a drilling fluid. It hydraulically shores the trench to prevent collapse, and, at the same time, forms a filter cake on the trench walls to prevent high fluid losses into the surrounding ground. Slurry wall types are differentiated by the materials used to backfill the slurry trench. Most commonly, an engineered soil mixture is blended with the bentonite slurry and placed in the trench to form a soil-bentonite (SB) slurry wall. In some cases, the trench is excavated under a slurry of portland cement, bentonite, and water, and this

mixture is left in the trench to harden into a cement-bentonite (CB) slurry wall. In the rare case where great strength is required of a subsurface barrier, pre-cast or cast-in-place concrete panels are constructed in the trench to form a diaphragm wall.

GROUT CURTAINS

Grout curtains are subsurface barriers created in unconsolidated materials by pressure injection. Grout barriers can be many times more costly as slurry walls and are generally incapable of attaining truly low permeabilities in unconsolidated materials. Recent field testing of two chemical grouts revealed significant problems in forming a continuous grout barrier due to noncoalescence of grout pods in adjacent holes, grout shrinkage and that conventional injection grouting is incapable of forming a reliable barrier in medium sands. Therefore, grout curtains are rarely used when groundwater control in unconsolidated materials is desired.

Grout curtains, like other barriers, can be applied to a site in various configurations. Circumferential placement offers the most complete containment but requires that grouting take place in contaminated groundwater downgradient of the source. Chemical reactors in groundwater can cause problems with grout set and durability. As with other techniques, this requires extensive compatibility testing during the feasibility study.. Another limitation of curtain grouting is the problem of gaps left in the curtain due to nonpenetration of the grout. Only a few small gaps in

an otherwise low permeability curtain can increase its overall permeability significantly.

SHEET PILING

Sheet piling can be used to form a groundwater barrier. Sheet piles can be made of wood, pre-cast concrete, or steel. Wood is an ineffective water barrier, however, and concrete is used primarily where great strength is required. Steel is the most effective in terms of groundwater cut-off and cost.

Because of costs and unpredictable wall integrity, sheet piling is seldom used except for temporary dewatering for other construction, or as erosion protection where some other barrier, such as a slurry wall, intersects flowing surface water.

One of the largest drawbacks of sheet piling, or any other barrier technology requiring pile driving, is the problem caused by rocky soils. Damage to or deflection of the piles is likely to render any such wall ineffective as a groundwater barrier.

VIBRATING BEAM

The vibrating beam method is not an injection technique usually used to install grout curtains, but instead is a way of placing grout so as to generate a wall. In this method, an I-beam is vibrated into the soil to the desired depth and then raised at a controlled rate. As the beam is raised, grout is pumped through a set of nozzles mounted in the

beam's base filling the newly formed cavity. When the cavity is completely filled, the beam is moved less than one beam width along the wall, leaving suitable overlap to ensure continuity (see Figure A-1).

CONCRETE WALLS

Concrete walls can be installed as vertical barriers to groundwater movement. The installation is similar to slurry wall construction with the exception that concrete is used to displace the mud slurry used to hold the trench open. Concrete has a narrower range of chemical compatibility and higher permeability than a conventional slurry wall (see Slurry Walls above).

CLAY WALLS

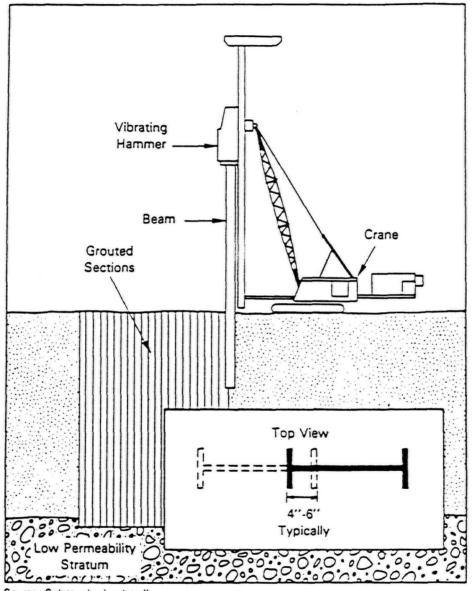
Clay walls can be installed as vertical barriers to groundwater movement. The installation is similar to slurry wall construction with the exception that clay materials are used to displace the mud slurry used to hold the trench open.

GROUTING DISPLACEMENT

Emplacement of a bottom seal by grouting involves drilling through the site, or directional drilling from the site perimeter, and injecting grout to form a horizontal or curved barrier. One such technique, jet grouting, involves drilling a pattern of holes across the site to the intended barrier depth. A special jet nozzle is lowered and a high pressure stream of air and water erodes the soil. By turning the nozzle through a complete rotation, a flat, circular cavity is formed.

FIGURE A-1

VIBRATING BEAM GROUT INJECTION



Source: Soletanche (undated)

The cavity is then grouted with intersecting grouted masses forming the barrier. The directional drilling method is very similar to curtain grouting except that it is performed in slanted rather than vertical boreholes.

BLOCK DISPLACEMENT

Block displacement is an experimental technique for isolating and raising a contaminated block of earth. By this technique, a perimeter barrier is constructed by slurry trenching or grouting. Grout is then injected into specially notched holes bored through the site. Continued grout or slurry pumping causes displacement of the block of earth isolated by the perimeter barrier and forms a bottom seal beneath the block.

This technique has been laboratory tested and field demonstrated at a nonhazardous site. It has yet to be attempted at and actual hazardous waste site and the technique is still being refined.

Source: EPA/625/6-85/006, Hand Book, Remedial Action At Waste Disposal Sites (Revised). October, 1985.

APPENDIX 11-1-2
TECHNOLOGY TYPES AND PROCESS OPTION DESCRIPTION

PHYSICAL TREATMENT PROCESSES

The processes described herein are those which utilize physical characteristics to effect a separation or concentration of constituents in a waste stream. The processes are organized into four groupings according to their physical basis, i.e., separation by gravity, separation by phase change, separation by dissolution and separation by size, adsorptivity, or ionic characteristics.

Gravity Separation:

- Sedimentation
- Centrifugation
- Flocculation
- Oil/Water Separation
- · Dissolved Air Flotation
- Heavy Media Separation

Phase Change:

- Evaporation
- · Air Stripping
- Steam Stripping
- Distillation

Dissolution:

- Soil Washing/Flushing
- Chelation
- Liquid/Liquid Extraction
- Supercritical Solvent Extraction

Size/Adsorptivity/Ionic Characteristics:

- Filtration
- Carbon Adsorption
- Reverse Osmosis
- Ion Exchange
- Electrodialysis

Important Physical Treatment Data Needs

Data Need

Purpose

For Solids

Absolute Density Density Separation

Bulk Density Storage Volume Required

Size Distribution Size Modification or Separation

Friability Size Reduction Solubility Dissolution

(in H2O, organic solvents, oils, etc.)

For Liquids

Specific Gravity Density Separation

Viscosity Pumping & Handling

Water Content Separation

(or oil content, etc.)

Dissolved Solids Separation

Boiling Pt/Freezing Point Phase Change Separation, Handling and Storage

For Liquids/Solid Mixtures

Bulk Density Storage & Transportation

Total Solids ContentSeparationSolids Size DistributionSeparationSuspended Solids ContentSeparationSuspended Solids Settling RateSeparationDissolved Solids ContentSeparation

Free Water Content Storage & Transport

Oil and Grease Content Separation

Viscosity Pumping and Handling

For Gases

Density Separation

Boiling (condensing) Temp. Phase Change Separation

Solubility (in H₂O, etc.) Dissolution

TECHNOLOGY: Sedimentation

DESCRIPTION: Sedimentation is a gravity settling process which allows heavier solids to collect at the bottom of a containment vessel resulting in its separation from the suspending fluid. This type of operation can be accomplished using a batch process or a continuous removal process. There exist several physical arrangements in which the sedimentation process can be applied. These are represented in the diagram shown. The top diagram illustrates a settling pond wherein aqueous waste flows through while the suspended solids are permitted to gravitate and settle out. Occasionally the settled particles (sludges) are removed so this system would be considered a semi-batch process. The middle figure shows a circular clarifier equipped with a solids removal device to facilitate clarification on a continuous process basis resulting in a lower solids content outlet fluid. The third type is a sedimentation basin, as shown in the bottom diagram. It uses a belt-type solids collector mechanism to force the solids to the bottom of the sloped edge of the basin where they are removed. The efficiency of sedimentation treatment is dependent upon the depth and surface area of the basin, settling time (based on the holding time), solid particle size and the flow rate of the fluid.

APPLICABILITY/LIMITATION: Sedimentation is considered to be a separation process only, and typically, some type of treatment process for the aqueous liquid and the sludges will follow. Its use is restricted to solids that are more dense than water and it is not suitable for wastes consisting of emulsified oils.

STATUS: Conventional

SOURCES: Chemical Waste Management Inc.
Dorr Oliver

Eimco Process Equipment Co.

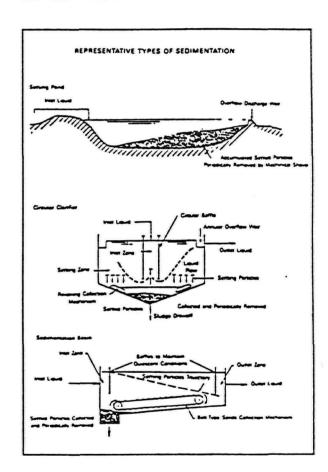
Wyo Ben Inc.

National Hydro Systems Inc. Sharples Stokes Div Pennwalt

Water Tech Inc. AFL Industries

Important Sedimentation Data Needs

Data Need	Purpose
Viscosity of aqueous waste	High viscosity hinders sedimentation
Oil and grease content of waste stream	Not applicable to wastes containing emulsified oils
Specific gravity of suspended solids	Must by greater than 1 for sedimentation to occur



TECHNOLOGY: Centrifugation

DESCRIPTION: Centrifugation is a physical separation process in which the components of a fluid mixture are separated, based on their relative density, by rapidly rotating the fluid mixture within a rigid vessel. Solid particles that are denser than the fluid medium are deposited farthest from the axis of rotation while the liquid supernatant lies separated near the axis. Centripetal forces in centrifugation are similar to gravitational forces in sedimentation except that centripetal forces are thousands of times stronger than gravitational forces, depending upon diameter and rotational speed of the centrifuge.

AVAILABILITY/LIMITATION: This treatment is limited to dewatering sludges (including metal-bearing sludges), separating oils from water, and clarification of viscous gums and resins. Centrifuges are generally better suited than vacuum filters for dewatering sticky or gelatinous sludges. Disc-type centrifuges can be used to separate three-component mixtures (e.g., oil, water, solids). Centrifuges often cannot be used for clarification since they may fail to remove less dense solids and those which are small enough to remain in suspension. Recovery and removal efficiencies may be improved if paper or cloth filters are incorporated in the centrifuges.

STATUS: Commercially available

SOURCES: Clinton Centrifuge Inc.

ALFA Laval Inc. Tetra Recovery Systems Dorr-Oliver Inc.

Bird Environmental Systems Western States Machine

Fletcher

Astro Metallurgical Barrett Centrifugals

Donaldson Co. Industrial Group Donaldson Co. Liquid Sys. Div.

GCI Centrifuges

General Productions Svcs Inc.

IT Corp.

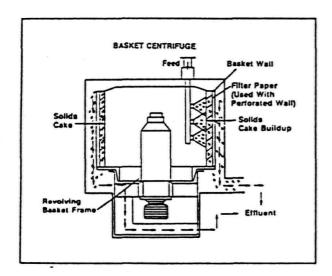
Ingersoll Rand Environmental Master Chemical Corp. Sys. Equip. Sartorius Bal Div. Brinkmann

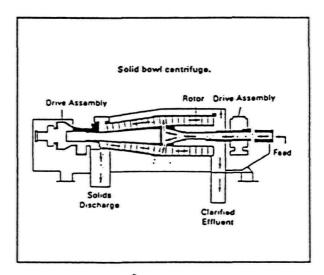
Sharples Stokes Div.

Pennwalt

Tekmar Co.

Thomas Scientific







TECHNOLOGY: Flocculation

DESCRIPTION: Flocculation is a treatment technology which is used to enhance sedimentation or centrifugation. The waste stream is mixed while a flocculating chemical is added. Flocculants adhere readily to suspended solids and with each other (agglomerate) so that the resultant particles are too large to remain in suspension. Flocculation is primarily used for the precipitation of inorganics.

AVAILABILITY/LIMITATION: The extent of completion of flocculation is dependent upon the flow rate of the waste stream, its composition and its pH. This process is not recommended for a waste stream with high viscosity.

STATUS: Conventional, demonstrated

SOURCES: Refer to buyer's guides

Important Flocculation Data Needs

Data Need	Purpose
pH of waste	Selection of flocculating agent
Viscosity of waste system	Affects settling of agglomerated solids; high viscosity not suitable
Settling rate of suspended solids	Selection of flocculating agent

TECHNOLOGY: Oil/Water Separation

DESCRIPTION: As in sedimentation, the force of gravity can be used to separate two (or more) immiscible liquids having sufficiently different densities, such as oil and water. Liquid/liquid separation occurs when the liquid mix is allowed to settle. Thus, flow rates in continuous processes must be kept low. The waste flows into a chamber where it is kept quiescent and permitted to settle. The floating oil is skimmed off the top through the use of an oil skimmer while the water or effluent flows out the lower portion of the chamber. Acids may be used to break an oil/water emulsion and enhance this process to allow for greater efficiency in removal of the oil.

AVAILABILITY/LIMITATION: The effectiveness of the separation process can be influenced by the waste stream's rate of flow, temperature, and pH. Separation constitutes a pretreatment process if the oil skimmings require further treatment.

STATUS: Mobile phase separators are commercially available

SOURCES: Refer to buyer's guides

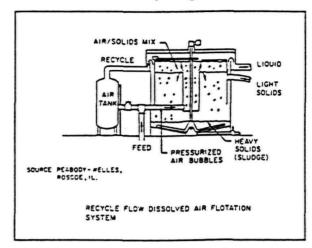
TECHNOLOGY: Dissolved Air Flotation

DESCRIPTION: Dissolved air flotation is a physical process whereby suspended particles or mixed liquids can be removed from an aqueous waste stream. The mixture to be separated is saturated with air (or some other gas such as nitrogen) and typically the pressure is reduced above the treatment tank. As air then comes out of solution, the microbubbles which form can readily adsorb onto suspended solids or oils, enhancing their "flotation" characteristics. In the flotation chamber, separated oil or other "floats" are skimmed off the top while the aqueous liquids flow off the bottom.

AVAILABILITY/LIMITATION: This technology is only applicable for waste having densities close to that of water. Air emission controls may be necessary if hazardous volatile organics are present in the waste.

STATUS: Conventional

SOURCES: Refer to buyer's guides



TECHNOLOGY: Heavy Media Separation

DESCRIPTION: Heavy media separation is a process for separating two solid materials which have significantly different absolute densities. The mixed solids to be separated are placed into a fluid whose specific gravity is chosen (or adjusted) so that the lighter solid floats while the heavier sinks. Usually, the separating fluid (the heavy media) is a suspension of magnetite in water. Specific gravity of the fluid is thus adjustable by varying the amount of magnetite powder used. Magnetite can be easily recovered magnetically from rinsewaters and spills and then reused.

AVAILABILITY/LIMITATION: This type of separation is readily used for separating two insoluble solids having different densities. Limitations include the possibility of dissolving solids and ruination of the heavy media, the presence of solids of similar density to those whose separation is desired and the inability to cost-offectively separate magnetic materials (because of the need to recover magnetite).

STATUS: Commonly used in the mining industry to separate ores from tailings

SOURCES: Tetra Recovery Systems
Enviro-Chem Waste Management
Service

TECHNOLOGY: Evaporation

DESCRIPTION: Evaporation is the physical separation of a liquid from a dissolved or suspended solid by the application of energy to volatilize the liquid. In hazardous waste treatment, evaporation may be used to isolate the hazardous material in one of the two phases, simplifying subsequent treatment. If the hazardous material is in the volatilized phase, the process is usually called "stripping." (See Air Stripping.)

AVAILABILITY/LIMITATION: Evaporation can be applied to any mixture of liquids and nonvolatile solids provided the liquid is volatile enough to evaporate under reasonable heating or vacuum conditions (both the liquid and the solid should be stable under those conditions). If the liquid is water, evaporation can be carried out in a large pond provided with solar energy. Evaporation of aqueous wastes can also be done in closed process vessels with energy provided by steam and the resulting water vapor can be condensed for possible reuse. Energy requirements are usually minimized by such techniques as vapor recompression or multiple effect evaporators. Evaporation is applied to solvent waste contaminated with nonvolatile impurities such as oil, grease, paint solids or polymeric resins. Mechanically agitated or wiped thin film evaporators are used. Solvent is evaporated and recovered for reuse. The residue is the bottom stream, typically containing 30 to 50% solids.

Consensate

Distribute Vapor
Fum

Pump

Consensate

Consensate

Chamber

Chamber

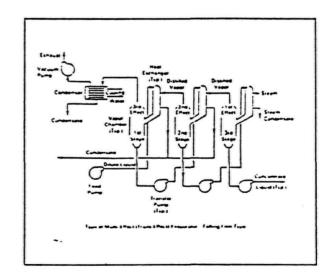
It areates
Pump

It areate

STATUS: Commercially available

SOURCES: Resources Conservation Company (mobile brine concentration systems) Kipin Industries APV Equipment Inc. Ambient Tech. Div. Ameribrom Inc. Analytical Bio Chem Labs Agua Chem Water Technologies Capital Control Co., Inc. Dedert Corp. HPD Inc. Industrial Filter & Pump Mfg. Kimre Inc. Kontro Co., Inc. Lancy International Inc. Licon Inc. Rosenmund Inc. Sasakura Intl American Corp. Spraying Systems Co. Votator Anco Votator Div. Wallace & Tiernan Div. Pennwalt Wastesaver Corp. Weathermeasure Weathertronics

Wheaton Instruments



TECHNOLOGY: Air Stripping

DESCRIPTION: Air stripping is a mass transfer process in which volatile contaminants, in water or soils, are evaporated into the air. Factors important in removal of organics from wastewater via air stripping are temperature, pressure, air to water ratio and surface area available for mass transfer. Air to water volumetric ratios may range from 10:1 up to 300:1. The resulting residuals are the contaminated off gas and the stripped effluent. Volatilized hazardous materials must be recaptured for subsequent treatment to preclude air pollution concerns.

AVAILABILITY/LIMITATION: This process is used to treat aqueous organic waste with relatively high volatility, low water solubility (e.g., chlorinated hydrocarbons such as tetrachloroethylene) and aromatics (such as toluene). Limitations include the fact that the process is temperature dependent so that stripping efficiency can be impacted by changes in ambient temperature and the presence of suspended solids may reduce efficiency. If the concentration of VOCs exceeds approximately 100 ppm, some other separation process (e.g., steam stripping) is usually preferred.

STATUS: Commercially available

SOURCES: OH Materials

Carbon Air Services

Detox Inc.
IT Corporation

Oil Recovery Systems Inc.

Resource Conservation Company

Terra Vac Inc.

Advanced Industrial Technology

Baron Blakeslee Inc. Beco Engineering Co. Calgon Carbon Corp.

Chem Pro Corp.

D. R. Technology Inc.

Delta Cooling Towers

Detox Inc.

Hydro Group Inc.

IPC Systems Inc.

IT Corp.

Kimre Inc.

Munters Corp.

NEPCCO

North East Environmental Prods.

Oil Recovery Systems Inc.

Tri-Mer Corp.

Wright R.E. Associates Inc.



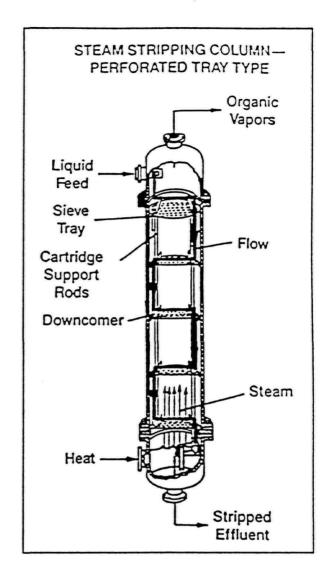
TECHNOLOGY: Steam Stripping

DESCRIPTION: The operation of steam stripping uses steam to evaporate volatile organics from aqueous wastes. Steam stripping is essentially a continuous fractional distillation process carried out in a packed or tray tower. Clean steam, rather than reboiled bottoms, provides direct heat to the column in which gas flows from the bottom to the top of the tower. The resulting residuals are contaminated steam condensate, recovered solvent and stripped effluent. The organic vapors and the raffinate are sent through a condenser in preparation for further purification treatment. The bottoms will require further consideration as well. Possible post-treatments may include incineration, carbon adsorption and land disposal.

AVAILABILITY/LIMITATION: Steam stripping is used to treat aqueous wastes contaminated with chlorinated hydrocarbons, aromatics such as xylenes, ketones such as acetone or MEK, alcohols such as methanol and high boiling point chlorinated aromatics such as pentachlorophenol. Steam stripping will treat less volatile and more soluble wastes than will air stripping and can handle a wide concentration range (e.g., from less than 100 ppm to about 10 percent organics). The steam stripping process requires some type of air pollution control (APC) mechanism to eliminate toxic emissions.

STATUS: Conventional, well demonstrated

SOURCES: Refer to buyer's guides



TECHNOLOGY: Distillation

DESCRIPTION: Distillation is simply the process of evaporation followed by condensation whereby separation of volatile materials can be optimized by controlling both the evaporation-stage temperature (and pressure) and the condenser temperature. Distillation separates miscible organic liquids for solvent reclamation and for waste volume reduction. The resulting residuals are still-bottoms (often containing toxic metals from ink and paint pigments) and intermediate distillate cuts. Two major types of distillation processes are batch distillation and continuous fractional distillation.

AVAILABILITY/LIMITATION: Distillation is used to separate liquid organic wastes, primarily spent solvents, for full or partial recovery and reuse. Both halogenated and nonhalogenated solvents can be recovered via distillation. Liquids to be separated must have different volatilities. Distillation for recovery can be limited by the presence of either volatile or thermally reactive suspended solids. If constituents in the input waste streams can form an azeotrope (a specific mixture of liquids exhibiting a maximum or minimum boiling point with the individual constituents) then the energy cost of breaking the azeotrope can be prohibitive.

Batch distillation in a heated still pot with condensation of the overhead vapors is easily controlled and flexible, but cannot achieve the highproduct purity typical of continuous fractional distillation. Small packaged batch stills treating

Condenser

Partial Recycle

Still

Stuam

Buttom

Product

one drum per day or less are becoming popular for on-site recovery of solvents. Continuous fractional distillation is accomplished in tray columns or packed towers ranging up to 40 feet in diameter and 200 feet high. Each is equipped with a reboiler, a condenser and an accumulator. The capacity of a unit is a function of the waste being processed, purity requirements, reflux ratio and heat input. Fractional distillation is not applicable for liquids with high viscosity at high temperature, liquids with a high-solids concentration, polyurethanes and inorganics.

STATUS: Commercially available

SOURCES: Exceltech, Inc.

Kipin Industries

Mobil Solvent Reclaimers, Inc.

APV Equipment Inc.

Ace Glass Inc.

Artisan Industries Inc.

Gilmont Instruments Inc.

Glitsch Inc.

Hoyt Corp.

Licon Inc.

Progressive Recovery Inc.

Rosenmund Inc.

Sutcliffe Croftshaw

Tekmar Co.

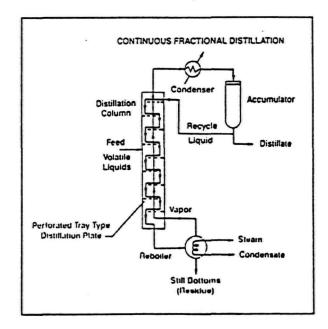
Thomas Scientific

Vara International Inc.

Vic Mfg Co. Industrial Div.

Wheaton Instruments

York Otto H. Co., Inc.



TECHNOLOGY: Chelation

DESCRIPTION: A chelating molecule contains atoms which can form ligends with metal ions. If the number of such atoms in the molecule is sufficient and if the final molecular shape is such that the metal atom is essentially surrounded then the metal will not be able to form ionic salts which can precipitate out. Thus, chelation is used to keep metals in solution and to aid in dissolution for subsequent transport and removal (e.g., soil washing).

APPLICABILITY/LIMITATION: Chelating chemicals can be chosen for their affinity to particular metals (e.g., EDTA and calcium). The presence of fats and oils can interfere with the process.

STATUS: Chelating chemicals are commercially available

SOURCES: Refer to buyer's guides

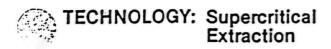
TECHNOLOGY: Liquid/Liquid Extraction

DESCRIPTION: Two liquids which are well mixed or are mutually soluble may be separated by liquid/liquid extraction. The process requires that a third liquid be added to the original mix. This third liquid must be a solvent for one of the original components, but must be insoluble in and immiscible with the other. The final solvent/solute stream can be subsequently separated by distillation or by chemical means and the extracting solvent captured for rouse.

AVAILABILITY/LIMITATION: Complete separation is rarely achieved, so that some form of post-treatment is required for each separated stream. To effectively recover solvent and solute from the process, other treatments are needed such as distillation or stripping.

STATUS: Demonstrated

SOURCES: Resources Conservation Co.



DESCRIPTION: At a certain combination of temperature and pressure, fluids reach their critical point, beyond which their solvent properties are greatly enhanced. For instance, supercritical water is an excellent non-polar solvent in which most organics are readily soluble. These properties make extraction more rapid and efficient than processes using distillation or conventional solvent extraction methods. Presently, the use of supercritical carbon dioxide to extract hazardous organics from aqueous streams is being investigated.

AVAILABILITY/LIMITATION: This technology is potentially useful to extract hazardous waste from aqueous streams. Specific applicability and limitations are not yet known.

STATUS: Demonstrated on laboratory scale

SOURCES: N/A



TECHNOLOGY: Filtration

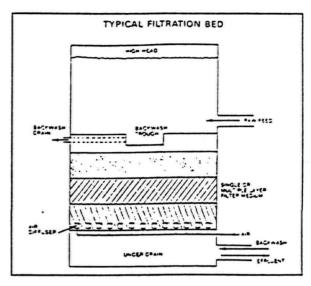
DESCRIPTION: Filtration is a process of separating and removing suspended solids from a liquid by passing the liquid through a porous medium. The porous medium may be a fibrous fabric-(paper or cloth), a screen, or a bed of granular material. The filter medium may be precoated with a filtration aid such as ground cellulose or diatomaceous earth. Fluid flow through the filter medium may be accomplished by gravity, by inducing a partial vacuum on one side of the medium, or by exerting a mechanical pressure on a dewaterable sludge enclosed by filter media.

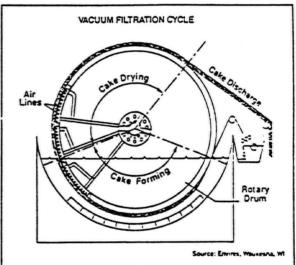
AVAILABILITY/LIMITATION: Filtration is used for the dewatering of sludges and slurries as a pretreatment for other processes. Granular media filtration is typically used after gravity separation processes for additional removal of suspended solids and oils prior to the other treatment processes. It is also used as a polishing step for treated waste to reduce suspended solids and associated contaminants to low levels. Pretreatment by filtration is appropriate for membrane separation processes, ion exchange, and carbon adsorption in order to prevent plugging or overloading of these processes. Filtration of settled wastes is often required to remove undissolved heavy metals which are present as suspended solids. Filtration does not reduce the toxicity of the waste although sometimes powdered activated carbon may be used as a combination adsorbent and filter aid. Filtration should not be used with sticky or gelatinous sludges, due to the likelihood of filter media plugging.

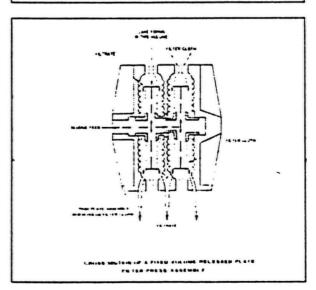
STATUS: Commercially available

SOURCES: Calgon Carbon Corp.

Carbon Air Services Inc.
Chemical Waste Management
Industrial Innovations Inc.
Krauss-Maffei
Komline Sanderson
Bird Machine Co.
D.R. Sperry Inc.
Dorr-Oliver







TECHNOLOGY: Carbon Adsorption

DESCRIPTION: The chemistry of carbon is such that most organic compounds and many inorganics will readily attach themselves to carbon atoms. The strength of that attachment (and thus, the energy required for subsequent desorption) depends on the bond formed, which in turn, depends on the specific compound being adsorbed. Carbon to be used for adsorption is usually treated to produce a product with large surface-to-volume ratio, thus, exposing a practical maximum number of carbon atoms to be active adsorbers. Carbon so treated is said to be "activated" for adsorption. Activated carbon which has adsorbed so much contaminant that its adsorptive capacity is severely depleted is said to be "spent." Spent carbon can be regenerated, but for strongly adsorbed contaminants, the cost of such regeneration can be higher than simple replacement with new carbon.

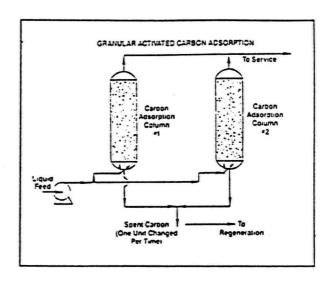
AVAILABILITY/LIMITATION: This process is used to treat single-phase aqueous organic wastes with high molecular weight and boiling point and low solubility and polarity, chlorinated hydrocarbons such as tetrachloroethylene, and aromatics such as phenol. It is also used to capture volatile organics in gaseous mixtures. Limitations are usually economic and relate to the rapidity with which the carbon becomes spent. Rule of thumb guidelines are that contaminant concentrations should be less than 10,000 ppm, suspended solids less than 50 ppm, dissolved inorganics and oil and grease less than 10 ppm.

STATUS: Conventional, demonstrated

SOURCES: Calgon Carbon Corp.
Carbon Air Services Inc.
Zimpro Inc.
Chemical Waste Mgt.

Important Carbon Adsorption Process

Data Need	Purpose
Chemical characterization of waste stream	Suitability for carbon treatment
Molecular weight	Suitability for carbon treatment
Solubility	Suitability for carbon treatment
Polarity of contaminants to be removed	Suitability for carbon treatment
pH of waste stream	Suitability for carbon treatment





TECHNOLOGY: Reverse Osmosis

DESCRIPTION: In normal osmotic processes, solvent will flow across a semi-permeable membrane from a dilute concentration to a more concentrated solution until equilibrium is reached. The application of high pressure to the concentrated side will cause this process to reverse. This results in solvent flow away from the concentrated solution, leaving an even higher concentration of solute. The semi-permeable membrane can be flat or tubular, but regardless of its shape it acts like a filter due to the pressure driving force. In application the waste stream flows past the membrane while the solvent, such as water, is pulled through the membrane's pores and the remaining solutes such as organic or inorganic components do not pass through, but become more and more concentrated on the influent side of the membrane.

AVAILABILITY/LIMITATION: For an efficient reverse osmosis process, the chemical and physical properties of the semi-permeable membrane must be compatible with the waste stream's chemical and physical characteristics. Some membranes may be dissolved by some wastes. Suspended solids and some organics will clog the membrane material. Low-solubility salts may precipitate onto the membrane surface.

STATUS: Commercial units are available

SOURCES: Osmo Membrane Systems

ECHNOLOGY: Ion Exchange

SCRIPTION: Although there are naturally occurring ion exchange media, the process is usually based on the use of specifically formulated resins having an "exchangeable" ion bound to the resin with a "weak ionic" bond. Ion exchange depends upon the electrochemical potential of the ion to be recovered versus that of the exchange ion, and also upon the concentration of the ions in solution. After a critical relative concentration of "recoverable" ion to exchanged ion in solution is exceeded, the exchange resin is said to be "spent." Spent resin is usually recharged by exposing it to a very concentrated solution of the original exchange ion so that a "reverse" exchange takes place, resulting in regenerated resin and a concentrated solution of the removed ion which can then be further processed for recovery and reuse. The process is commonly used to remove toxic metal ions from solution in order to recover concentrated metal solutions for recycling. The resulting residuals include spent resins and spent regenerants such as acid, caustic or brine.

AVAILABILITY/LIMITATION: This technology is used to treat metal wastes including cations a.g., Ni²⁺, Cd²⁺, Hg²⁺) and anions (e.g., 0²-, Se0²-, HAs0²-). Limitations are selectiv/competition, pH and suspended solids. Highly concentrated waste streams (greater than about 25,000 mg/l contaminants) can usually be separated more cost effectively by other means. High solid concentrations (greater than about 50 mg/l) should be avoided to prevent resin blinding.

STATUS: Commercially available

SOURCES: Calgon Dionex

DeVoe-Holbein

Davis Instrument Mfg Co., Inc. Ecology Protection systems Inc.

Envirex Inc.

Industrial Filter & Pump Mfg.

Lancy International Inc.

McCormack Corp.

Osmo Membrane Sys Div.

Pace International Corp.

Permutit Co., Inc.

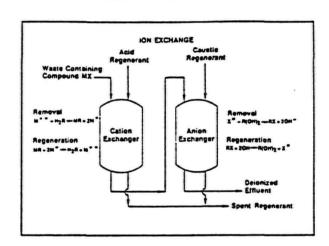
Serfilco LTD.

Techni Chem., Inc.

Thomas Scientific

Treatment Technologies

Water Management Inc. Western Filter Co.



TECHNOLOGY: Electrodialysis

DESCRIPTION: Electrodialysis concentrates or separates ionic species contained in a water solution. In electrodialysis, a water solution is passed through alternately placed cation-permeable and anion-permeable membranes. An electrical potential is applied across the membrane to provide the motive force for the ion migration. The ion-selective membranes are thin shoets of ion exchange resin reinforced by a synthetic fiber backing.

AVAILABILITY/LIMITATION: The process is well established for purifying brackish water, and recently has been demonstrated for recovery of metal salts from plating rinse.

STATUS: Units are being marketed to reclaim metals of value from rinse streams. Such units can be skid mounted and require only piping and electrical connections.

SOURCES: Contoc Corp.

CHEMICAL TREATMENT PROCESSES

The treatment processes discussed in this section include most of those commonly used for waste treatment applications. These include

- pH Adjustment (for Neutralization or Precipitation)
- · Hydrolysis and Photolysis
- Oxidation and Reduction
- Hydrogen Peroxide Oxidation
- Ozonation
- · Alkaline Chlorination
- · Hypochlorite Chlorination
- Electrolytic OxidationChemical Dechlorination

Important Chemical Treatment Data Needs*

Data Need	Purpose
рН	pH Adjustment Needs, Corrosivity
Turbidity/Opacity	Photolysis
Consitituent analysis	Treatment Need
Halogen Content	Dehalogenation

^{*} Generally, the data needs for evaluating and comparing chemical treatment technologies include the data needs identified for physical treatment technologies

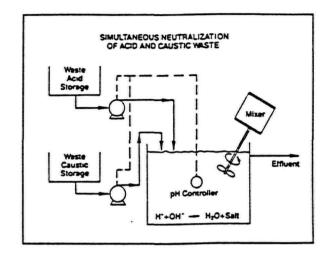
TECHNOLOGY: Neutralization

DESCRIPTION: When an ionic salt is dissolved in water, several of the water molecules break into their ionic constituents of H+ and OH-. Neutralization is the process of changing the constituents in an ionic solution until the number of hydrogen ions (H +) present is balanced by the number of hydroxyl (OH -) ions. The lack of balance is measured in terms of the hydrogen ion (H +) concentration and is commonly called the pH of the solution. Neutrality is given on the pH scale as 7, while an excess of H + ions (acidity) is a number between 0 and 7 and an excess of hydroxide ions (OH -) (alkalinity) is indicated by a number between 7 and 14. Neutralization is used to treat waste acids and waste alkalies (bases) in order to eliminate or reduce their reactivity and corrosiveness. Neutralization can be a very inexpensive treatment, especially if waste alkali can be used to treat waste acid and vice/ versa. Residuals include a neutral effluent containing dissolved salts and any precipitated salts.

APPLICABILITY/LIMITATION: The process should be performed in a well-mixed system to ensure completeness. Care should be taken to ensure compatibility of the waste and treatment chemicals to prevent the formation of more toxic or more hazardous compounds than were originally present.

STATUS: Common industrial process

SOURCES: Refer to buyer's guides for chemical suppliers





TECHNOLOGY: Chemical Precipitation

DESCRIPTION: Like neutralization, chemical precipitation is a pH adjustment process. To achieve precipitation, acid or base is added to a solution to adjust the pH to a point where the constituents to be removed have their lowest solubility. Chemical precipitation facilitates the removal of dissolved metals from aqueous wastes. Metals may be precipitated from solution as hydroxides, sulfides, carbonates, or other insoluble salts. Hydroxide precipitation with lime is most common, however, sodium sulfide is sometimes used to achieve lower effluent metal concentrations. Solid separation is effected by standard flocculation/coagulation techniques. The resulting residuals are metal sludge and the treated effluent which has an elevated pH and (in the case of sulfide precipitation) excess sulfide.

APPLICABILITY/LIMITATION: This technology is used to treat aqueous wastes containing metals. Limitations include the fact that not all metals have a common optimum pH at which they precipitate. Chelating and complexing agents can interfere with the process. Organics are not removed except through adsorptive carryover. The resulting sludge may be hazardous by definition but often may be delisted by specific petition.

STATUS: Commercially available

SOURCES: Mobile Systems-Rexnord Craig

Ecolochem Inc. Dravo Corp. Detox Inc.

Envirochem Waste Management

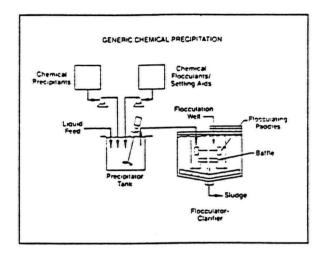
Services

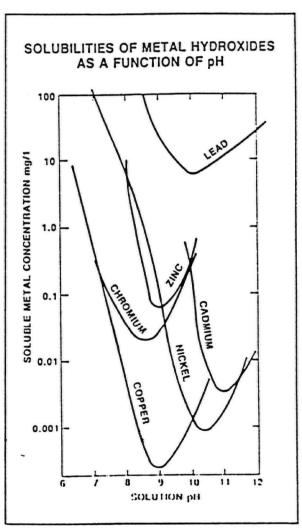
Chemical Waste Management Inc. Andco Environmental Processes

Inc.

Ensotech Inc.

Tetra Recovery Systems





TECHNOLOGY: Ultraviolet Photolysis

DESCRIPTION: Ultraviolet photolysis (UV) is a process that destroys or detoxifies hazardous chemicals in aqueous solutions utilizing UV irradation. Adsorption of energy in the UV spectrum results in a molecule's elevation to a higher energy state, thus, increasing the ease of bond cleavage and subsequent oxidation of the molecule. For example, ultraviolet light has been used for degradation of dioxins in waste sludge. This process requires extraction of the waste to be destroyed into a clean transparent solvent. Reaction products are dechlorinated materials and free chlorine gas. Use of UV photolysis on

nitrated wastes has been successfully demonstrated on a pilot scale.

APPLICABILITY/LIMITATION: The inability of UV light to penetrate and destroy pollutants in soil or in turbid or opaque solutions is a limitation of this approach. Photolytic treatment can be enhanced by simultaneous introduction of ozone or hydrogen peroxide.

STATUS: Laboratory scale

SOURCES: SYNTEX

TECHNOLOGY: Chemical Oxidation (Chemical Reduction)

DESCRIPTION: Oxidation and reduction must both take place in any such reaction. In any oxidation reaction the oxidation state of one compound is raised (I.e., oxidized) while the oxidation state of another compound is lowered (i.e., reduced). Oxidation and reduction reactions are utilized to change the chemical form of a hazardous material in order to render it less toxic or to change its solubility, stability, separability or otherwise change it for handling or disposal purposes. In the reaction, the compound supplying the oxygen (or chlorine or other negative ion) is called the oxidizer or oxidizing agent while the compound accepting the oxygen (i.e., supplying the positive ion) is called the reducing agent. The reaction can be enhanced by catalysis, electrolysis or irradiation.

The process is called chemical reduction when its purpose to lower the oxidation state of a compound. Typical reducing agents include: iron, aluminum, zinc and sodium compounds.

For the reduction process to occur efficiently, the pH of the waste should be adjusted to an appropriate level. After this stage is accomplished, the reducing agent is added and the resulting solution is mixed until the reaction is completed. This treatment may be applied to chemicals such as hexavalent chromium, mercury and lead. It is likely that other treatment processes may be used in conjunction with chemical reduction.

APPLICABILITY/LIMITATION: The process is nonspecific. Solids must be in solution. Reactions can be explosive. Waste composition must be well known to prevent the inadvertant production of a more toxic or more hazardous end product.

STATUS: Conventional process

SOURCES: Refer to buyer's guides for specific process application

TECHNOLOGY: Oxidation by Hydrogen Peroxide (H₂0₂)

DESCRIPTION: This treatment technology is based on the addition of hydrogen peroxide to oxidize organic compounds. Hydrogen peroxide is not the stable oxide of hydrogen and since it readily gives up its extra oxygen, it is an excellent oxidizing agent.

APPLICABILITY/LIMITATION: The process is a nonspecific reaction. It may be exothermic/explosive or require addition of heat and/or catalysts. Oxidation by hydrogen peroxide is probably not applicable for in-situ treatment. However, it may be used for surface treatment of contaminated groundwaters/sludges.

STATUS: Common industrial process

SOURCES: Refer to buyer's guides

ECHNOLOGY: Ozonation

JESCRIPTION: Ozone is an oxygen molecule containing three oxygen atoms. It is relatively unstable and thus, is chemically ideal as an oxidizing agent. Ozonation is a chemical oxidation process appropriate for aqueous streams which contain less than 1 percent oxidizable compounds.

APPLICABILITY/LIMITATION: Ozone can be used to pretreat wastes to break down refractory organics or as a polishing step after biological or other treatment processes to oxidize untreated organics. Ozone is usually produced by high-voltage ionization of atmospheric oxygen

(O₂). Ozone is currently used for treatment of hazardous wastes to destroy cyanide and phenolic compounds. The rapid oxidation of cyanides with ozone offers advantages over the slower alkaline chlorination method. Limitations include the physical form of the waste (i.e., sludges and solids are not readily treated) and non-selective competition with other species.

STATUS: Commercially available

SOURCES: Refer to buyer's guides

TECHNOLOGY: Alkaline Chlorination

DESCRIPTION: When chlorine is added to wastewaters, under alkaline conditions, reactions occur which lead to oxidation (chlorinaon) of the contaminant. This oxidation process, hich is widely used in the treatment of cyanide wastes, is generally referred to as the "alkaline chlorination" process. Cyanides can be oxidized with chlorine to the less toxic cyanates. Additional chlorine will then oxidize the cyanates to nontoxic nitrogen gas, carbon dioxide, and bicarbonates.

APPLICABILITY/LIMITATION: Alkaline chlorination is used to treat free cyanides and com-

plex cyanides although combinations with Fe or Ni will take a longer time. Limitations include the exothermic heat of the reaction, non-selective competitions with other species and additional chlorine demands. Fairly close pH control (7.5 to 9.0) is required to avoid toxic volatiles release.

STATUS: Commercially available

SOURCES: Refer to buyer's guides

TECHNOLOGY: Oxidation by Hypochlorite

DESCRIPTION: This process consists of adding sodium or calcium hypochlorite (bleaching agents) to oxidize organic wastes. Such technology will be recognized as the common method of disinfecting home swimming pools.

APPLICABILITY/LIMITATION: This method may produce toxic chlorinated organic by-products and it must be done under controlled (not in-situ)

conditions, i.e. batch reactors. It is a nonspecific reaction.

STATUS: Commercially available

SOURCES: Refer to buyer's guides

TECHNOLOGY: Electrolytic Oxidation

DESCRIPTION: In this process cathodes and anodes are immersed in a tank containing a waste to be oxidized, and a direct electrical current is imposed on the system. The process is particularly applicable to cyanide bearing wastes. Reaction products are ammonia, urea, and carbon dioxide. During the decomposition, metals present are plated out on the cathodes.

APPLICABILITY/LIMITATION: Electrolytic oxidation is used to treat high concentrations (up to ~10 percent) of cyanide and to separate met-

als to allow their potential recovery. Limitations include physical form of the feed (solids must be dissolved), non-selective competition with other species and long-process times. Electrolytic recovery of single metal species can be high (90 percent and higher).

STATUS: Commercially available

SOURCES: Refer to buyer's guides

TECHNOLOGY: Catalytic Dehydrochlorination

DESCRIPTION: Catalytic Dehydrochlorination is based on the reaction of polychlorinated hydrocarbons with high pressure hydrogen gas in the presence of a catalyst. The feed must be in either a liquid or gaseous form with the inorganic and inert constituents removed. The operating temperatures are: 350 to 375°C under 30 to 50 atm pressure. The quantity of catalysts is usually less than 1 percent of pollutant weight.

APPLICABILITY/LIMITATION: In general, supported catalysts are quickly deactivated by impurities such as tars or sulfur compounds. These processes are costly and often require the use of hazardous chemicals as catalysts.

STATUS: Laboratory scale

SOURCES: Not applicable

TECHNOLOGY: Alkali Metal Dechlorination

DESCRIPTION: The purpose of this process of chemical dechlorination is to displace chlorine from chlorinated organic compounds contained in oils and liquid wastes. Typically the waste is filtered before it enters the reactor system where it encounters the dechlorinating reagent. The great affinity of alkali metals for chlorine (or any halide) is the chemical basis of the process. Successive treatment includes additional centrifugation and filtration. By-products include chloride salts, polymers and sometimes heavy metals. This process may be carried out in a reactor system (as mentioned above), in situ or by excavation techniques. Several chemical dechlorination processes are based on a method developed by the Goodyear Tire and Rubber Company in 1980. The original method uses sodium naphthalene and tetrahydrofuran to strip chlorine atoms from PCBs, resulting in polymerizing the biphenols into an inert condensible sludge. The reactor is blanketed with nitrogen because reagents are sensitive to air and to

water and an excess of reagent to chlorine content is required. The Goodyear Company has not commercially developed the technology. However several companies have modified the method by substituting their own proprietary reagent for the naphthalene. The equipment is mobile and can be transported on semi-trailors.

APPLICABILITY/LIMITATION: Such processes are used to treat PCBs, other chlorinated hydrocarbons, acids, thiols, and dioxins. Moisture content adversely affects rates of reaction and dewatering should be a pretreatment step. Waste stream concentrations are also important.

STATUS: Commercially available

SOURCES: American Mobile Purification

SunOhio PPM Inc. Acurex

Chemical Waste Management Inc.

Exceltech, Inc.

TECHNOLOGY: Alkali Metal/ Polyethylene Glycol (A/PEG)

DESCRIPTION: In 1978, the EPA sponsored research which led to the development of the first of the series of A/PEG reagents, which were shown to effectively dechlorinate PCBs and oils. Essentially, these reagents were alkali metall polyethylene glycols which react rapidly to dehalogenate halo-organic compounds of all types, under both ambient and high temperature conditions. In the A/PEG reagents, the alkali metal ion is held in solution by the large polyethylene glycol anion. PCBs and other halogenated molecules are uniquely soluble in A/PEG reagents. These qualities combine to get a single-phase system in which the anions readily displace the halogen atoms. The reaction of halogenated aromatics with PEGs result in the substitution of the PEG for the chloring atom to form a PEG ether. The PEG other, in turn, may then decompose to a phonol.

APPLICABILITY/LIMITATION: In this treatment, heat and excess reagent are required for the process to function effectively in soils containing more than seven percent moisture.

STATUS: Process has been field tested

SOURCES: Not applicable

BIOLOGICAL PROCESSES

Biological degradation of hazardous organic substances is a viable approach to waste management. The most commonly used processes are those originally utilized in the treatment of municipal wastewaters, namely, processes based on aerobic bacteria or anaerobic bacteria. In-situ treatment of contaminated soils can also be performed biologically. Cultures used in biological degradation processes can be native (indigenous) microbes, selectively adapted microbes or genetically altered microorganisms.

Some processes based on other biological communities (such as fungi) are under development and evaluation, but have not been fully demonstrated.

Important Biological Treatment Data Needs

Data Need	Purpose
Gross Organic Component (BOD, TOC)	Treatability
Priority Pollutant Analysis	Toxicity to Process Microbes
Dissolved Oxygen	Aerobic Reaction Rates/ Interference with Anaerobic System
Nutrient Analysis (NH ₃ , NO ₃ , PO ₄ , etc.)	Nutrient Requirements
pH	pH Adjustment
ORP	Chemical Competition



DESCRIPTION: Hydrocarbons are catabolized (broken down to simpler substances) by microorganisms using three general mechanisms. These are aerobic respiration, anaerobic respiration and fermentation. In general, aerobic degradation processes are more often used for biodegradation because the degradation process is more rapid and more complete, and problematic end products (methane, hydrogen sulfide) are not produced. However, anaerobic degradation is important for dehalogenation. (See anaerobic process description in this document).

In aerobic respiration, organic molecules are oxidized to carbon dioxide (CO2) and water and other end products using molecular oxygen as the terminal electron acceptor. Oxygen may also be incorporated into intermediate products of microbial catabolism through the action of oxidase enzymes, making them more susceptible to further biodegradation. Microorganisms metabolize hydrocarbons by anaerobic respiration in the absence of molecular oxygen using inorganic substrates as terminal electron acceptors. Naturally occurring aerobic bacteria can decompose organic materials of both natural and synthetic origin to harmless or stable forms or both by mineralizing them to CO2 and water. Some anthropogenic compounds can appear relatively refractory to biodegradation by naturally occurring microbial populations because of the interactions of environmental influences, lack of solubility, absence of required enzymes, nutrients, or other factors. However, the use of properly selected or engineered microbial populations, maintained under environmental conditions most conducive to their metabolic activity can be an important means of biologically transforming or degrading these otherwise refractory wastes.

All microorganisms require adequate levels of inorganic and organic nutrients, growth factors

(vitamins, magnesium, copper, manganese, sulfur, potassium, etc.), water, oxygen, carbon dioxide and sufficient biological space for survival and growth. One or more of these factors are usually in limited supply. In addition, various microbial competitors adversely affect each other through the struggle for these limiting factors. Other factors which can influence microbial biodegradation rates include microbial inhibition by chemicals in the waste to be treated, the number and physiological state of the organisms as a function of available nutrients, the seasonal state of microbial development, predators, pH and temperature. Interactions between these and other potential factors can cause wide variations in degradation kinetics. For these and other reasons, aerobic biodegradation is usually carried out in processes in which all or many of the requisite environmental conditions can be controlled. Such processes include conventional activated sludge processes as well as modifications such as sequencing batch reactors, and aerobic-attached growth biological processes such as rotating biological contactors and trickling filters. Recent developments with genetically engineered bacteria have been reported to be effective for biological treatment of specific hazardous wastes which are relatively uniform in composition.

APPLICABILITY/LIMITATION: Used to treat aqueous wastes contaminated with low levels (e.g., BOD less than ≈ 10,000 mg/ℓ) of nonhalogenated organic and/or certain halogenated organics. The treatment requires consistent, stable operating conditions.

STATUS: Conventional, broadly used technology

SOURCES: Dependent upon specific engineered approach — see following discussions

TECHNOLOGY: Activated Sludge

DESCRIPTION: The function of activated sludge treatment is to break down organic contaminants in aqueous waste streams through the activity of aerobic microorganisms. These microorganisms metabolize biodegradable organics. This treatment includes conventional activated sludge processes as well as modifications, such as sequencing batch reactors. The aeration process includes pumping the waste to an aeration tank where the biological treatment occurs. Following this the stream is sent to a clarifier where the liquid effluent (treated aqueous waste) is separated from the sludge biomass. Aerobic processes are capable of significantly reducing a wide range of organic, toxic and hazardous compounds. However, only dilute aqueous waste (less than = 1 percent) are normally treatable.

APPLICABILITY/LIMITATION: The treatment requires consistent stable operating conditions. Activated sludge processes are not suitable for removing highly chlorinated organics, aliphatics, amines and aromatic compounds from a waste stream. Some heavy metals and organic chemicals are harmful to the organisms. When utilizing conventional open aeration tanks and clarifiers, this technology can result in the escape of volatile hazardous materials.

STATUS: Conventional, well developed

SOURCES: Polybac Corp.
Detox Inc.
Ground Decontamination Systems

ACTIVATED SLUDGE PROCESS

Nutnerst Addition, N and/or P

Influent

Return
Sludge

Waste
Sludge
Pump



TECHNOLOGY: Rotating Biological Contactors

DESCRIPTION: Rotating biological contactors aerobically treat aqueous waste streams, especially those containing alcohols, phenols, phthalates, cyanides and ammonia. The process consists of primary treatment for solids removal followed by the rotating biological contactors where the waste stream comes into contact with the microbial film and the atmosphere. The rate of rotation can be varied to optimize oxygenation of the bacteria and their contact time with the wastes to be degraded. Effluent is then sent to a secondary clarifier.

APPLICABILITY/LIMITATION: Rotating biological contactors are not a sufficient method to remove highly chlorinated organics, aliphatics, amines and aromatic compounds. Some heavy metals and organic chemicals are harmful to the organisms.

STATUS: Conventional

SOURCES: Polybac Corp.
Detox Inc.
Ground Decontamination Systems

Important Data Needs for Screening RBCs:

Data Need	Purpose			
Gross organic components (BOD, TOC)	Waste strength, treatment duration			
Priority pollutant analyses (organics, metals, pesticides, CN, phenols)	Suitability for treatment, toxic impact assessment			
Influent temperature	Feasibility in climate			

TECHNOLOGY: Bioreclamation

DESCRIPTION: Bioreclamation is used to treat contaminated areas through the use of aerobic microbial degradation. It may be accomplished by in-situ treatment using injection/extraction wells or an excavation process. Extracted waters, leachates or wastes are oxygenated, nutrients and bacteria are added and the liquids reinjected in the ground. Bacteria then can degrade wastes still in the soil. The treatment has been successfully applied to biodegradable nonhalogenated organics to reduce the contaminated levels in soils and groundwater.

APPLICABILITY/LIMITATION: For in-situ treatment, limitations would include site geology and hydrogeology which could restrict pumping and extraction of hazardous wastes, along with reinjection and recirculation. Ideal soil conditions are those with neutral pH, high permeability and a moisture content of 50 to 75 percent.

STATUS: Domonstrated

SOURCES: FMC

Important Bioreclamation Data Needs

Data Need	Purpose
Gross organic components (BOD, TOC)	Waste strength, treatment duration
Priority analysis	Identify refractory and biodegradable compounds, toxic impact
Microbiology cell enumerations	Determine existence of dominant bacteria
Temperature	Feasibility in climate
Dissolved oxygen	Rate of reaction
рН	Bacteria preference
Nutrient analysis NH ₃ , NO ₃ , PO ₄ , etc.	Nutrient requirements

TECHNOLOGY: Anaerobic Digestion

DESCRIPTION: All anaerobic biological treatment processes achieve the reduction of organic matter, in an oxygen-free environment, to methane and carbon dioxide. This is accomplished by using cultures of bacteria which include facultative and obligate anaerobes. Anaerobic bacterial systems include hydrolytic bacteria (catabolize saccharides, proteins, lipids); hydrogen producing acetogenic bacteria (catabolize the products of hydrolytic bacteria, e.g., fatty acids and neutral end products); homolactic bacteria (catabolize multicarbon compounds to acetic acid); and methanogenic bacteria (metabolize acetic and higher fatty acids to methane and carbon dioxide). The strict anaerobes require totally oxygen-free environments and oxidation reduction potential of less than -0.2V. Microorganisms in this group are commonly referred to as methanogenic consortia and are found in anaerobic sediments or sewage sludge digesters. These organisms play an important role in reductive dehalogenation reactions, nitrosamine degradation, reduction of epoxides to olefins, reduction of nitro groups and ring fission of aromatic structures. Available anaerobic treatment concepts are based on such approaches as the classic well-mixed system, the two-stage systems and the fixed bed. In the well-mixed digester system a single vessel is used to contain the wastes being treated and all bacteria must function in that common environment. Such systems typically require long retention times and the balance between acetogenic and methanogenic populations is easily upset. In the two stage approach, two vessels are used to maintain separate environments, one optimized for the acetogenic bacteria (pH 5.0), and the other optimized for the methanogenic bacteria (pH 7.0). Retention times are significantly lower and upsets are uncommon in this approach. The fixed bed approach (for single or 2-staged systems) utilizes an inert solid media to which the bacteria attach themselves and low solids wastes are pumped through columns of such bacteria rich media. Use of such supported cultures allows reduced retention times since bacterial loss through washout is minimized. Organic degradation efficiencies can be quite high. A number of proprietary engineered processes based on these types of systems are actively being marketed, each with distinct features but all utilizing the fundamental anaerobic conversion to methane and carbon dioxide.

APPLICABILITY/LIMITATION: This process is used to treat aqueous wastes with low to moderate levels of organics. Anaerobic digestion can handle certain halogenated organics better then aerobic treatment. Stable, consistent operating conditions must be maintained. Anaerobic degradation can take place in native soils but when used as a controlled treatment process, an airtight reactor is required. Since methane and CO2 gases are formed, it is common to vent the gases or burn them in flare systems. However, volatile hazardous materials could readily escape via such gas venting or flare systems. Thus, controlled off-gas burning could be required. Alternatively, depending on the nature of the waste to be treated, the off-gas could be used as a source of energy.

STATUS: Available and widely used in POTWs

SOURCES: Refer to buyer's guides

ECHNOLOGY: White-rot Fungus

DESCRIPTION: The lignin degrading white-rot fungus (phanerochaete chrysosporium) has been found to degrade a broad spectrum of organopollutants including chlorinated ligninderived by-products of the Kraft pulping process. White-rot has been shown to degrade aliphatic, aromatic and heterocyclic compounds. Specifically, white-rot fungus has been shown to degrade lindane, benzo(a)pyrene, DDT, TCDD, and PCBs to innocuous end products. The studies performed, to date, suggest that white-rot fungus may prove to be an extremely useful microorganism in the biological treatment of hazardous organic waste.

APPLICABILITY/LIMITATION: Demonstrated on laboratory scale

STATUS: This technology is in the developmental phase and has been applied only in laboratory-type test environs

SOURCES: N/A

THERMAL DESTRUCTION PROCESSES

While limits exist for specific incineration technologies, there are no "a priori" technical limitations on incineration for any wastes, i.e., any waste can be burned at some cost. Thermal destruction processes include several energy recovery processes, traditional incineration processes and several innovative thermal processes.

Data Need	ermal Treatment Data Needs* Purpose	
Heat Content (HHV and LHV)	Combustibility	
Volatile Matter Content	Furnace Design	
Ash Content	Furnace Design, Ash Handling	
Ash Characteristics	Furnace Design	
Halogen Content	Refractory Design, Flue Gas Ductwork Specification, APC Requirements	
Moisture Content	Auxiliary Fuel Requirements	
Heavy Metal Content	Air Pollution Control	

^{*} Generally, the data needs for evaluating thermal processes includes the data needed for physical treatment for the purpose of feed mechanism design



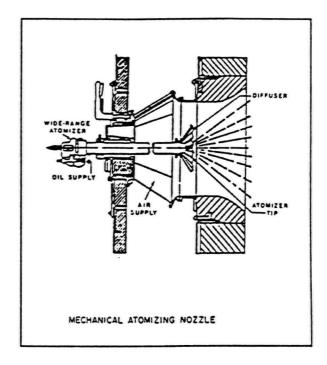
TECHNOLOGY: Liquid Injection Incineration

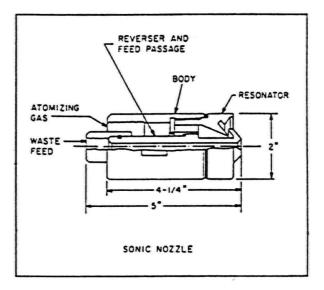
DESCRIPTION: Liquid waste material is introduced to the combustion chamber by means of specially designed nozzles. Different nozzle designs result in various droplet sizes which mix with air and fuel as needed. Following combustion, the resulting gases are cooled and treated to remove particulates and to neutralize acid gases. Pretreatment such as blending, may be required for feeding some wastes to specific nozzles to provide efficient mixing with the oxygen source and to maintain a continuous homogeneous waste flow. In general, the more finely atomized liquids will combust more rapidly and more completely. Operating temperatures range from 1200 to 1300° F and the gas residence time ranges from 0.1 to 2 seconds. Typical heat output ranges from 1 to 100 MMBtu/ hr.

APPLICABILITY/LIMITATION: Liquid injection incineration can be applied to all pumpable organic wastes including wastes with high moisture content. Care must be taken in matching waste (especially viscosity and solids content) to specific nozzle design. Particle size is a relevant consideration so the wastes do not clog the nozzle. Emission control systems will probably be required for wastes with ash content above 0.5 percent (particulate control) or for halogenated wastes (acid gas scrubbers).

STATUS: This process is conventional and well demonstrated

SOURCES: Ensco Environmental Services TRANE Thermal Co. John Zink Co. Coen Co. Inc. Vent-o-Matic Incinerator Corp. Lotepro Co.





TECHNOLOGY: Rotary Kiln Incineration

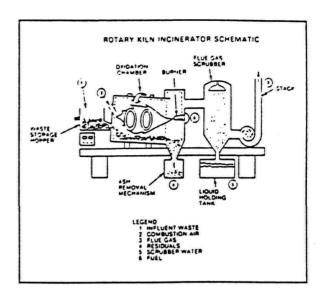
DESCRIPTION: A rotary kiln incinerator is essentially a long, inclined tube that is rotated slowly. Wastes and auxiliary fuels are introduced to the high end of the kiln and the rotation constantly agitates (tumbles) the solid materials being burned. This tumbling causes a great amount of turbulence and allows for improved combustion. Rotary kilns are intended primarily for solids combustion, but liquids and gases may be co-incinerated with solids. Exhaust gases from the kiln pass to a secondary chamber or afterburner for further oxidation. Ash residue is discharged and collected at the low end of the kiln. Exhaust gases require acid gas and particulate removal through the use of a gas scrubber and the ashes may require solidification before landfilling.

APPLICABILITY/LIMITATION: Most types of solid, liquid, and gaseous organic waste or a mixture of these wastes can be treated with this technology. Explosive wastes and wastes with high inorganic salt content and/or heavy metals require special evaluation. This operation can create high particulate emissions which require post-combustion control.

STATUS: Rotary kiln incinerators are commercially available and are in wide use.

SOURCES: S.D. Myers, Inc.

American Industrial Waste of ENCSO, Inc., (mobile)
Exceltech, Inc.
Coen Co.
International Waste Energy
Systems
Thermal, Inc.
Lurgi Corp.
Komline Sanderson
International Waste Energy System
Winston Technology, Inc., (mobile)
Volland, U.S.A.
Von Roll
DETOXCO Inc.



TECHNOLOGY: Fluidized Bed Incineration

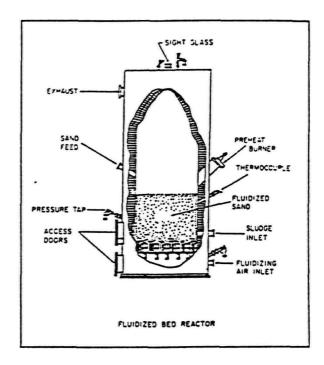
DESCRIPTION: Fluidized bed incinerators utilize a very turbulent bed of inert granular material (usually sand) to improve the transfer of heat to the waste streams to be incinerated. Air is blown through the granular bed materials until they are "suspended" and able to move and mix in a manner similar to a fluid, i.e., they are "fluidized." In this manner, the heated bed particles come in intimate contact with the wastes being burned. The process requires that the waste be fed into multiple injection ports for successful treatment.Advantages of this technology include excellent heat transfer to the material being incinerated and a long residence time. An off-shoot of this technology is a circulating bed combustor.

APPLICABILITY/LIMITATION: Fluidized beds require frequent attention for maintenance and cleaning purposes. This treatment is ideal for slurries and sludges but not for bulky or viscous wastes. The waste particles should be of a certain size and be homogeneous. Wastes must have a low sodium content and a low heavy metal content. Some refractory wastes may not be fully destroyed since these units operate at low combustion temperatures (750° to 1000° C).

STATUS: Fluidized bed incineration is presently available in a demonstration-scale unit for hazardous waste. They have been used to incinerate municipal wastewater treatment plant sludge, oil refinery waste, some pharmaceutical wastes, and some chemical wastes including phenolic waste, and methyl methacrylate. Heat recovery is possible.

SOURCES: Lurgi Corp.

G.A. Technologies
Waste-Tech Services, Inc.
Dorr-Oliver
Combustion Power
Niro Atomizer





TECHNOLOGY: Pyrolysis

DESCRIPTION: Pyrolysis is the chemical decomposition of waste brought about by heating the material in the absence of oxygen. The system involves the use of two combustive chambers. In the primary chamber the wastes are heated, separating the volatile components (combustible gases, water vapor, etc.) from the nonvolatile char and ash (metals and salts). In the secondary chamber (afterburner or fume incinerator) volatile components are burned under the proper air, temperature, time and turbulence to destroy any remaining hazardous components. Temperature in the pyrolysis section is controlled by the addition of auxiliary fuel. There are two ways to heat the material; the first is by direct heating where the material comes in contact with hot combustion gases from a burner or incinerator. The resulting off-gas is a combination of the combustion gases and the volatiles from the waste. The second method is by indirect heating by an electric resistance heating element or an external burner with its exhaust gases directly vented to the atmosphere. This approach allows product recovery, rather than incineration, from the gaseous stream leaving the primary chamber without contamination or dilution by the burner flue gases. Indirect heating is more complex and expensive than direct heating. Pyrolysis can be designed for batch burning of drummed or containerized material

or continuous processing of flowable solids and liquids. The hot combustion gases from the secondary chamber can be passed through a boiler to recover energy. Liquid wastes can be injected simultaneously into the secondary chamber during the pyrolyzing of waste in the primary chamber.

APPLICABILITY/LIMITATION: This technology is used to treat viscous liquids, sludges, solids, high-ash material, salts and metals or halogenated waste that are not conducive to conventional incineration, wastes that are stored in containers or which contain volatile metals or recoverable residues. The limitations are that it requires auxiliary fuel, currently has small capacity of waste input and metals and salts in the residue can be leachable, thus, requiring residue disposal as a hazardous waste.

STATUS: Commercially available, batch and continuous pyrolysis processes exist.

SOURCES: Midland-Ross Corp.

American Energy Corp.
Econo Therm Energy Systems
Lurgi Corp.
J.M. Huber Corp.
Shirco Infrared Systems, Inc.
Spencer Boiler and Engineering,
Inc.

ECHNOLOGY: Wet Air Oxidation

DESCRIPTION: Wet air oxidation uses elevated temperature and pressure to oxidize dissolved or finely divided organics. The oxidation products usually remain dissolved or suspended in the liquid. The off-gas is low in nitrogen oxides, sulfur oxides and particulates. Off-gas treatment may be necessary to control hydrocarbon emissions. The advantages are, it is thermally self sustaining, accepts waste with organic concentrations ranging between those considered ideal for either biological treatment or incineration, detoxifies priority pollutants and the products of oxidation stay in the liquid phase. Wet air oxidation is particularly well suited for treating organic compounds in aqueous waste streams that are too dilute (less than 5 percent organics) to treat economically by incineration. Oxidation of the organic compounds occurs when the aqueous solution is heated to about 300° C and 137 atm in the presence of compressed air. Typically, 80 percent of the organic substances will be completely oxidized. The

system can accommodate some partially halogenated compounds, but highly-chlorinated species, such as PCBs, are too stable for complete destruction without the addition of catalysts or the use of very high pressure and temperature.

APPLICABILITY/LIMITATION: This process is used to treat aqueous waste streams with less than 5 percent organics and with some pesticides, phenolics, organic sulfur and cyanide wastewaters. It is not recommended for aromatic halogenated organics, inorganics or for treating large volumes of waste. This technology is not appropriate for solids or viscous liquids.

STATUS: Available at commercial scale

SOURCES: Zimpro Inc.

Modar Inc.

Vertox Treatment Systems

ECHNOLOGY: Industrial Boilers

DESCRIPTION: Some industrial boilers can use limited amounts and types of wastes as supplemental fuels so that the wastes are destroyed while recovering the available heat from the waste. Hazardous waste is used as supplementary fuel to coal, oil or natural gas in fire-tube and water-tube industrial boilers. Hazardous waste fuel (generally limited to liquid waste) can be fed into a boiler with the primary fuel or it can be fed separately into the furnace. If a facility is burning its own wastes as fuel, it can control "fuel quality" to a great extent. If wastes are imported for use as fuel, then it is common to blend incoming wastes to an "optimum" supplemental fuel for that facility's boilers.

APPLICABILITY/LIMITATION: Chlorine and sulfur must be limited in Hazardous Waste Fuel (HWF) to minimize corrosion of boiler materials

of construction and to avoid increases in HCl and sulfur oxide air emissions. Solid hazardous wastes such as contaminated soil are not applicable for use as HWF in boilers. Industrial boilers are particularly useful for the disposal of hazardous waste generated on site.

STATUS: Only a small fraction of the nation's 23,000 fossil-fueled boilers are in use burning hazardous waste as fuel.

SOURCES: Various manufacturers, may be packaged units or field constructed



TECHNOLOGY: Industrial Kilns (Cement, Lime, Aggregate, Clay)

DESCRIPTION: Industrial kilns are used to incinerate liquid wastes while recovering heat value. The system consists of rotary kilns constructed of steel casings lined with refractory brick. These kilns are much longer than rotary kiln incinerators and have much longer retention times. Blended feed material (a waste/air mixture) is fed into the hot end of the kiln as a supplement to the primary fuel (coal, gas, or oil). Kiln temperatures are about 3000° F for cement and lime kilns and less than 2000° F for aggregate and clay drying kilns. Organics are destroyed while the ash is assimilated into the kiln product. Waste blending is necessary to obtain desired fuel characteristics to control product quality. The kiln should contain a precipitator or baghouse in order to remove suspended particulates in the flue gases.

APPLICABILITY/LIMITATION: Kilns have generally been limited to liquid waste. Heavy metals,

ash, chlorine and sulfur content of waste fuel must be controlled to prevent kiln operating and product quality problems. Contaminated soils are not good candidates for treatment in industrial kilns because of concern for product quality. The system should be equipped with air pollution control devices.

STATUS: The use of hazardous waste as a fuel in kilns is becoming more widespread. At least 15 cement kilns and at least six aggregate kilns are now burning hazardous waste fuel as supplemental fuels in the U.S. This technology can be considered conventional and well demonstrated.

SOURCES: SYSTECH Corp.

PATCHEM - Waste Management McKesson Envirosystems Co.

TECHNOLOGY: Blast Furnaces

DESCRIPTION: Blast furnace temperatures may reach up to 3400° F and are generally above 3000° F. High heat content hazardous wastes can be used to supplement the fuel requirements for blast furnaces. A blast furnace produces molten iron from iron ore and other iron bearing feed materials. Iron ore, carbon (coke) and limestone are fed to the top of the furnace, and iron product and slag are removed in different layers from the bottom. Hazardous wastes used as fuels can be injected above the slag layer.

APPLICABILITY/LIMITATION: The composition (trace elements) of the waste must be controlled to avoid product quality problems. Waste oils were fired in a blast furnace in HWERL test programs. Some concerns have been expressed that the reducing atmosphere in a blast furnace could result in reduced DREs.

STATUS: There are less than 80 blast furnaces currently operating in the U.S. The authors are aware of none that are currently burning hazardous waste as fuel.

SOURCES: N/A

ECHNOLOGY: Infrared Incineration

DESCRIPTION: Infrared radiators can be used as the heat source in the destruction of hazardous waste. This system is made up of a primary chamber consisting of a rectangular carbon steel box lined with layers of a light-weight, ceramic fiber blanket. Infrared energy is provided by silicon carbide resistance heating elements. The material to be processed is conveyed through the furnace on a woven wire belt. Solids are pyrolyzed on the hearth. Sufficient air (or oxygen) is introduced to fully combust the offgases. When the waste reaches the discharge end of the furnace it drops off the belt into a hopper. The advantages include a quiescent combustion zone which results in low particulate emission, reduced gaseous pollutant emissions, low fossil fuel usage, and up to 50 percent operational turndown capacity. This system allows a high degree of control and long-residence times for solids are achievable.

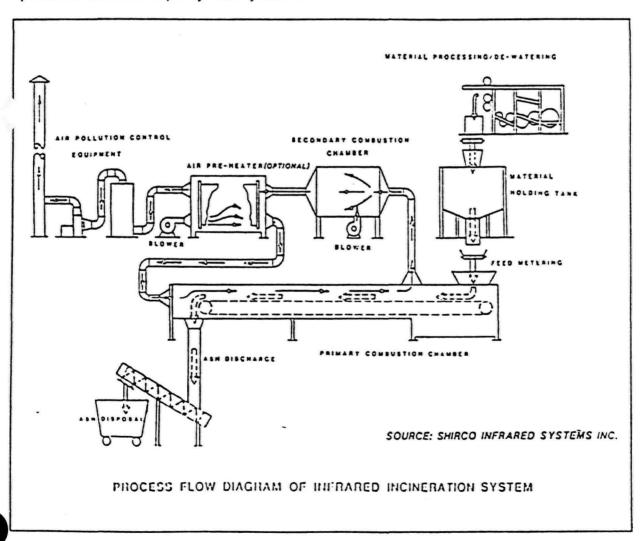
APPLICABILITY/LIMITATION: This technology is used primarily to treat solids (not larger than a specified size) sludges and contaminated soils, but liquid or gaseous injection systems are available.

STATUS: Operational units exist at several locations, mobile units are under construction and units are presently under evaluation in the SITE Program.

SOURCES: Shirco Infrared Systems

Haztech Maecorp Inc.

Reidel Environmental Services



TECHNOLOGY: Circulating Bed Combustor

DESCRIPTION: The circulating bed combustor is designed to be an improvement over conventional fluidized beds. The system operates at higher velocities and finer sorbents than fluidized bed systems. This permits a unit that is more compact and easier to feed. The unit also produces lower emissions and uses less sorbent materials than the fluidized bed systems. No off-gas scrubber is necessary in the circulating bed combustor and heat can be recovered as an added benefit. The key to the high efficiency of the circulating bed combustor is the high turbulence that is achieved within the combustor. This feature allows efficient destruction of all types of halogenated hydrocarbons including PCBs and other aromatics at temperatures less than 850° C (Freeman, 1985). Acid gases are captured within the combustion chamber by limestone in the bed. A baghouse is needed for particulate control. Compounds containing high levels of phosphorus, sulfur, cyanide, etc. can be processed with low emissions of NO_x, CO and acid gases. In addition to the turbulence, a large combustion zone with uniform and lower temperature throughout also contributes to high efficiency. The circulating bed combustor also features longer residence time of the combustibles and sorbents in the combustion zone.

APPLICABILITY/LIMITATION: The system is capable of treating solids, sludges, slurries and liquids. The high degree of turbulence and mixing ensures treatment of a wide variety of wastes. The waste however, must be fairly homogeneous in composition when fed to the combustor, since it is usually introduced at only one location. An additional benefit of the circulating bed combustor is the possibility of heat recovery. The combustion chamber can be of "waterwall" construction.

STATUS: Ready for full-scale testing. Unit is in RCRA permit process.

SOURCES: G. A. Technologies Riley Stoker Keeler Dorr-Oliver

TECHNOLOGY: Supercritical Water Oxidation

DESCRIPTION: The supercritical water oxidation process is basically a high temperature, high pressure wet air oxidation. The unique properties of water above 500° C (supercritical region) causes it to act as an excellent nonpolar solvent for nearly all organic materials. Aqueous solutions or slurries (organic content greater than 5 percent) are mixed with high pressure oxygen (3200 to 3600 psi or greater than 218 atm), to chemically oxidize waste in less than one minute at greater than 99.99 percent efficiency.

Two processing approaches have been evaluated, an above ground pressure vessel reactor (Modar) and the use of an 8000 to 10,000 ft deep well as a reactor vessel (Vertox). The supercritical water process is best suited for large volume (200 to 1000 gpm) dilute (in the range of 1 to 10,000 mg/t COD) aqueous wastes that are of a volatile nature and that have a sufficiently high heat content to sustain the process. In many applications, high Btu, nonhazardous waste can be mixed with low Btu hazardous waste to pro-

vide the heat energy needed to make the process self sustaining. Emissions/residues include gaseous effluent (nitrogen and carbon dioxide), precipitate of inorganic salts and the liquid containing only soluble inorganic acids and salts. The advantages are rapid oxidation rates, complete oxidation of organics, efficient removal of inorganics and no off-gas processing is required.

APPLICABILITY/LIMITATION: Supercritical water oxidation is used to treat aqueous organic solutions/slurries and mixed organic/inorganic waste, which are pumpable. Sophisticated equipment and operations and long term continuous operations have not been demonstrated, thereby limiting its use.

STATUS: Demonstration of use with municipal sewage sludge completed in 1985

SOURCES: Vertox Corporation Modar Inc.

TECHNOLOGY: Advanced Electric Reactor

DESCRIPTION: Advanced electric reactors use electrically heated fluid walls to pyrolyze waste contaminants. The resulting thermal radiation causes pyrolysis of the organic constituents in the waste feed. At these high temperatures inorganic compounds melt and are fused into vitreous solids. Most metal salts are soluble in these molten glasses and can thus become bound in a solid matrix (vitrified beads). Following pyrolysis in the reactor, granular solids and gaseous reactor emissions are directed to a post reactor zone, where radiant cooling occurs. The advantages are that it is transportable, has a high treatment efficiency and emissions are low.

APPLICABILITY/LIMITATION: This process is used to treat organics or Inorganics, in solid,

liquid or gaseous form (solid or liquid may require pretreatment) and for PCB or dioxin contaminated soils. It is limited to treating solids less than 35 US mesh and liquids atomized to less than 1500 micron droplets. A post treatment process may be needed in order to remove products of incomplete combustion from the emissions.

STATUS: Demonstrated on a pilot scale

SOURCES: Thagard Research Corp.
J. M. Huber Construction

TECHNOLOGY: Molten Salt Destruction

DESCRIPTION: Molten salt combustion is a method of burning organic material while, at the same time, sorbing the objectionable byproducts of that combustion from the effluent gas stream. This process of simultaneous combustion and sorption is accomplished by mixing the air and waste into a pool of molten sodium carbonate. The melt is maintained at temperatures between 1500 to 2000° F, causing the hydrocarbons of the organic matter to be oxidized to carbon dioxide and water, while elements such as phosphorus, sulfur, arsenic and the halogens react with the sodium carbonate. These by-products are retained in the melt as inorganic salts and eventually build up and must be removed in order that the molten bed remain fluid and retain its ability to absorb acidic cases. An ash concentration in the melt of up to approximately 20 percent by weight is acceptable.

APPLICABILITY/LIMITATION: Molten salt can be used to treat low ash or high chlorine content wastes. Low water content is required and the molten salt produced can be corrosive. The neutralization of acid gases results in the formation of other salts that can change the fluidity of the bed and hence require frequent replacement of the material. Used salts must be landfilled.

STATUS: Developmental, pilot-scale unit available

SOURCES: Rockwell International

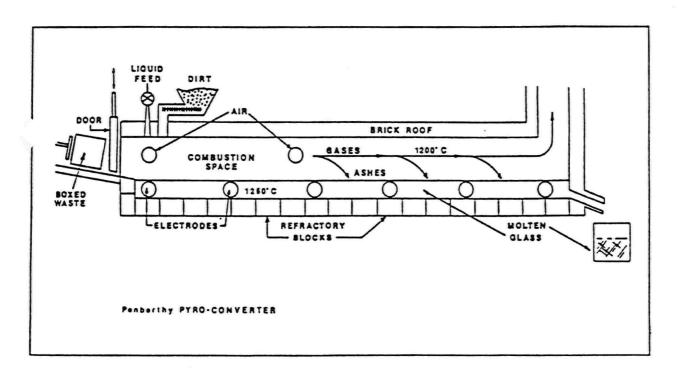
ECHNOLOGY: Molten Glass

DESCRIPTION: This technology uses a pool of molten glass as the heat transfer mechanism to destroy organics and to capture ash and inorganics. The emissions include acid gas and any particulates while all residues are contained in the glass. The advantages include significant volume reduction, most wastes are treatable and the residual is stabilized, nonbreaking glass. The process is based on existing glass making technology.

APPLICABILITY/LIMITATION: Molten glass can be used to treat any solid or liquid such as plastics, asphalts, PCB or pesticides. Sodium sulfates greater than 1 percent of the final glass may pose a problem. It is inappropriate for soils or high ash waste and it requires additional treatment for off-gas.

STATUS: The process is commercially available for uses other than hazardous waste incineration

SOURCES: Penberthy Electromelt International Inc.
Battelle-Northwest
Westinghouse Electric Corp.



TECHNOLOGY: Plasma Torch

DESCRIPTION: The plasma arc process functions by contacting the waste feed with a gas which has been energized into its plasma state by an electrical discharge. The plasma torch acts as one electrode and the hearth at the bottom of the reactor acts as the second electrode. The discharge of electricity between the two electrodes causes the centerline temperatures in the plasma to reach 9000° F. A small amount of gas is introduced into the centerline region and is ionized. The ionized gas molecules transfer energy to the waste to cause pyrolysis of the waste. Since the process is pyrolytic the scale of the equipment is small considering the high throughput rates. This characteristic makes it potentially attractive for use as a mobile unit. Gaseous emissions (mostly H₂, CO), acid gases in the scrubber and ash components in scrubber water are the residuals. The system's advantages are that it can destroy refractory compounds and typically the process has a very short on/off cycle.

APPLICABILITY/LIMITATION: This process is applicable to liquid (pumpable) organic wastes and finely divided, fluidizable sludges. It may be particularly applicable to the processing of liquid wastes with a high chlorine, pesticide, PCB or dioxin content. Sludges must be capable of being fluidized by the addition of a liquid. Waste streams must be free of (or preprocessed to remove) solids, which prevent satisfactory atomization.

STATUS: The application of plasma arc technology to hazardous waste treatment is hindered by a lack of operating experience. At this time, the only operating plasma arc system that is beyond the research and development stage is a pilot-scale mobile unit capable of 1 gal/min. of waste. Westinghouse is developing this mobile unit for the SITE Program.

VENDORS: Westinghouse Electric Corp.
Arc Technologies

FIXATION/STABILIZATION PROCESSES

The intent of these processes is to immobilize the toxic and hazardous constituents in the waste. This can be done by changing the constituents into immobile (insoluble) forms, binding them in an immobile, insoluble matrix and/or binding them in a matrix which minimizes the material surface exposed to solvent exposure. Each of the processes described herein accomplishes immobilization by one or more such methods. Often the immobilized product has structural strength sufficient to help protect itself from future fracturing (and concomitant exposure of additional "leachable" surfaces). Most of these processes are proprietary.

Important Fixation/Stabilization Treatment Data Needs

	Need
uala	MEEU

Purpose

The data needed is generally the same as that for both physical and chemical treatment processes.

rechnology: Lime-Based Pozzolan Processes

DESCRIPTION: This technology treats wastes and contaminated soils by the addition of large amounts of siliceous materials combined with a setting agent such as lime, cement or gypsum. Such treatment results in a dewatered stabilized solidified product.

APPLICABILITY/LIMITATION: This stabilization/ solidification process is used for sludges and contaminated soils. Contaminants can include metals, waste oils, and solvents. Materials such as borates, sulfates, and carbohydrates interfere with the process. Long-term stability and resistance to leaching is good for some wastes but is unknown for others.

STATUS: Commercially available

SOURCES: Different silicate processes available

TECHNOLOGY: Portland Cement Pozzolan Process

DESCRIPTION: This treatment is a minor variant of the lime pozzolan process. This stabilization treatment mixes the waste with portland cement to incorporate the waste into the cement matrices.

APPLICABILITY/LIMITATION: This process is effective for metal cations, latex and solid plastic wastes. Large amounts of dissolved sulfate salts or metallic anions such as arsenate and borates will hamper solidification. Organic matter, lignite, silt or clay in the wastes will increase setting time.

STATUS: Commercially available

SOURCES: Aerojet Energy Conversion Co.
ATCOR, Inc.
Chem-Nuclear System, Inc.
Delaware Custom Materials
Energy, Inc.
General Electric Co.
Hittman Nuclear and Development
Co.
Stock Equipment Co.
Todd Research and Technical Div.
United Nuclear Industries
Westinghouse Electric Co.

TECHNOLOGY: Sorption

DESCRIPTION: Contaminants are bound up in pozzolan-type matrices by physical sorption or chemisorption yielding a stabilized material which is easier to handle. Liquid immobilization depends on added ingredients. This process results in high concentrations of contaminants at the surface of the material and contaminants may leach. The treated material is permeable.

APPLICABILITY/LIMITATION: The process is suitable for organics and inorganics. Advantages to this technology include the fact that raw materials are plentiful and inexpensive, waste handling is improved, minimal pretreatment is required and the product's bearing

strength is adequate for landfill disposal. Disadvantages include the fact that large volumes of additives are required (albeit they are plentiful and cheap) so that waste volumes to be disposed are greatly increased. Furthermore, leachate control is highly variable, free water may be released under high pressure and there is temperature sensitivity.

STATUS: In common use for treatment of metal sludges removed from aqueous waste streams

SOURCES: Chemical Waste Management TRICIL Environmental

TECHNOLOGY: Vitrification

DESCRIPTION: Vitrification is a process whereby hazardous wastes are converted into a glassy substance utilizing very high temperatures. The process is carried out by inserting large electrodes into contaminated soils containing significant levels of silicates. Graphite on the surface connects the electrodes to the soil. High current of electricity passes through the electrodes and graphite. The heat causes a melt that gradually works downward through the soil. Some contaminant organics are volatilized and escape from the soil surface and must be collected by a vacuum system. Inorganic and some organics are trapped in the melt, which, as it cools, becomes a form of obsidian or very strong glass. When the melt is cooled, it forms a stable noncrystalline solid.

APPLICABILITY/LIMITATION: Vitrification was originally tested as a means of solidification/immobilization of low level radioactive metals. It may also be useful for forming barrier walls. This latter use needs testing and evaluation to determine how uniform the wall would be and stability of the material over a period of time.

STATUS: Demonstrated on a field scale

SOURCES: Battelle Northwest

ECHNOLOGY: Asphalt-Based (Thermoplastic) Microencapsulation

DESCRIPTION: This technology involves the mixing of heated dried waste within either an asphalt bitumen, paraffin, or polyethylene matrix, resulting in a stable solid waste mass. The advantages are: waste volume reduction, low permeability, elimination of free liquids, improved handling and good strength.

APPLICABILITY/LIMITATION: This method is applicable to hazardous waste that are complex and difficult to treat. Waste that should not be treated using this technology are: waste with high-water content, strongly oxidizing contaminants, anhydrous inorganic salts, tetraborates,

iron and aluminum salts, and organics with low molecular weights and high vapor pressures (volatile). The disadvantages include the fact that process equipment and materials can be expensive and there is some potential for air pollution.

STATUS: Commercially available

SOURCES: Werner A. Pfleidier
Aerojet Energy Conversion Co.
Newport News Industrial Corp.

TECHNOLOGY: Polymerization

DESCRIPTION: Polymerization uses catalysts to convert a monomer or a low-order polymer of a cricular compound to a larger chemical mulple of itself. Often, such large polymers have greater chemical, physical and biological stability than the monomers (or dimers or trimers) of the same chemical.

APPLICABILITY/LIMITATION: This technology treats organics including aromatics, aliphatics, and oxygenated monomers such as styrene, vinyl chloride, isoprene, and acrylonitrile. It has application to spills of these compounds.

STATUS: Has been used on spills

SOURCES: Refer to buyer's guides for sources of catalysts

TECHNOLOGY: Chemical Hydrolysis

DESCRIPTION: Hydrolysis is the process of breaking a bond in a molecule (which is ordinarily not water soluble) so that it will go into ionic solution with water. Hydrolysis can be achieved by the addition of chemicals (e.g., acid hydrolysis), by irradiation (e.g., photolysis) or biologically (e.g., enzymatic bond cleavage). The cloven molecule can then be further treated by other means to reduce toxicity.

APPLICABILITY/LIMITATION: Chemical hydrolysis is applicable to a wide range of otherwise

refractory organics. Acid hydrolysis as in-situ treatment must be performed carefully because of the potential to mobilize any heavy metals present.

STATUS: Common industrial process

SOURCES: Refer to buyer's guides for chemical suppliers

TECHNOLOGY: CRUSHED LIMESTONE PERMEABLE TREATMENT BED

Description: Crushed limestone is used as an in situ treatment of groundwater for heavy metals. Acidic groundwater is neutralized as it flows through the treatment bed with a subsequent removal of heavy metals.

Applicability/Limitation: Crushed limestone is readily available and relatively inexpensive. The treatment is not applicable to organics. Limitations include occasional cementing resulting in reduced flow through the bed or channeling with in the bed.

TECHNOLOGY: ACTIVATED CARBON BED

Description: See Chemical Treatment-Carbon sorbtion.

Applicability/Limitation: Used for a treatment of nonpolar organic compounds. Activated carbon is readily available and easy to install. The treament is not effective for inoganics. Limitations include: gradual reduction of sorbtion capacity, expensive removal and replacement costs, the potential for plugging, and potential interference with removal efficiency from nonorganic chemicals.

TECHNOLOGY: GLAUCONITIC SAND BED

Description: Glauconitic sand is used for removal of heavy metals from groundwater. Removal of metals requires only short residence times. Relatively small amounts of the material is required for treatment.

Applicability/Limitation: Glauconitic sand is abundant in eastern portions in the United States but more scarce in the west. Disadvantages include:

- 1) Reduction of pH as a result of treatment.
- Bed plugging may occur.
- 3) Saturation characteristics are unknown.
- 4) The ability to remove high concentrations from groundwater are not known.

TECHNOLOGY: CHEMICAL FIXATION

Description: See Fixation/Stabilization Process in this appendix.

TECHNOLOGY: AERATION

Description: Aeration is used to treat volatile organic contaminants in groundwater and in vadose zone soils. Aeration can include removal of vapors by soil venting, injection of air into unsaturated or saturated soils, or a combination of venting and injection.

Applicability/Limitation: Limitations can include site geology and hydrogeology. Fine grained sediments could restrict extraction or injection efficiency.

TECHNOLOGY: Soil Flushing/ Soil Washing

DESCRIPTION: Soil flushing is an in-situ extraction of inorganic or organic compounds from soils and is accomplished by passing extractant solvents through the soils using an injection/recirculation process. These solvents may include: water, water surfactant mixtures, acids or bases (for inorganics), chelating agents, oxidizing agents or reducing agents. Soil washing consists of similar treatments, but the soil is excavated and treated at the surface in a soil washer.

AVAILABILITY/LIMITATION: Soil flushing/washing fluids must have good extraction coefficients, low volatility and toxicity, be safe and easy to handle, and (most important), be recoverable/ recyclable. This technology is very

promising for extraction of heavy metals from soils, although problems are likely in dry, or in organic-rich soils. Surfactants can be used to extract hydrophobic organisms. Soil characteristics such as type and uniformity are important. Certain surfactants, when tested for in-situ extraction, clogged soil pores and precluded further flushing.

STATUS: U.S. EPA Edison, New Jersey, has mobile soil washer, other systems are under development

SOURCES: Critical Fluid Systems IT Corp.

TECHNOLOGY: Bioreclamation

DESCRIPTION: Bioreclamation is used to treat contaminated areas through the use of aerobic microbial degradation. It may be accomplished by in-situ treatment using injection/extraction wells or an excavation process. Extracted waters, leachates or wastes are oxygenated, nutrients and bacteria are added and the liquids reinjected in the ground. Bacteria then can degrade wastes still in the soil. The treatment has been successfully applied to biodegradable nonhalogenated organics to reduce the contaminated levels in soils and groundwater.

APPLICABILITY/LIMITATION: For in-situ treatment, limitations would include site geology and hydrogeology which could restrict pumping and extraction of hazardous wastes, along with reinjection and recirculation. Ideal soil conditions are those with neutral pH, high permeability and a moisture content of 50 to 75 percent.

STATUS: Domonstrated

SOURCES: FMC

Important Bioreclamation Data Needs

Data Need	Purpose
Gross organic components (BOD, TOC)	Waste strength, treatment duration
Priority analysis	Identify refractory and biodegradable compounds, toxic impact
Microbiology cell enumerations	Determine existence of dominant bacteria
Temperature	Feasibility in climate
Dissolved oxygen	Rate of reaction
рН	Bacteria preference
Nutrient analysis NH ₃ , NO ₃ , PO ₄ , etc.	Nutrient requirements

APPENDIX 11-3-1 METHODOLOGY AND RESULTS OF BENCH SCALE TREATABILITY TESTING OF PLANT SITE GROUNDWATER

SUMMARY OF JANUARY 1990 GROUNDWATER BENCH SCALE TESTING

PURPOSE:

Laboratory bench scale testing was conducted to evaluate the effectiveness of chemical precipitation of arsenic and metals from groundwater using sodium hypochlorite, magnesium hydroxide, ferric chloride and PERCOL 710. Testing was aimed at checking feasibility of coprecipitation of arsenic with iron for groundwater treatment. Groundwater from monitoring well DH-17 was selected for testing, as it is representative of water chemistry at the center of the groundwater plume.

EQUIPMENT AND REAGENTS:

Bench scale testing was conducted using a six position magnetic stirrer (jar tester) and 600 ml graduated beakers.

Stock reagents were:

- Clorox 5.25% sodium hypochlorite

- FeCl₃ 21.8% solution Mg(OH)₂ slurry (47,000 mg/L) PERCOL 710 solution (a polyelectrolyte used to induce floc growth)

PROCEDURE:

Various combinations of the reagents were tried with differing results. Outlined here is the procedure with optimum results. Results of other reagent combinations are also discussed.

Sodium hypochlorite was added to six 400 ml samples of groundwater from well DH-17 and flash-mixed for approximately 15 seconds. This flash-mixing is meant to ensure thorough mixing of reagents. Slow mixing (20 rpm) with the magnetic stirrer was continued throughout the remainder of the treatment.

Five minutes after the sodium hypochlorite addition, varying dosages of ferric chloride were added simultaneously to each sample and flash-mixed for approximately 15 seconds. Flash-mixing was followed by titration with magnesium hydroxide to the desired pH $(7.5 \le pH \le 9.0)$. Slow mixing continued for two hours after final pH adjustment.

After the slow mixing period settling characteristics and sludge volumes were recorded. PERCOL 710 was then added, flash-mixed for 15 seconds, and slow mixed for three minutes. Settling characteristics and settled sludge volumes were again recorded for all samples.

After settling tests, two 120 ml samples of the supernatant were collected from each beaker. One sample was drawn through a syringe from the middle of the supernatant. The second sample was filtered through a 0.45 micron filter. Samples were shipped to the DOES laboratory in Salt Lake City for analysis.

RESULTS:

Chemical analysis of untreated groundwater from monitoring well DH-17 collected on January 18, 1990 is in Table 1. Treatment procedures are summarized in Table 2 and results are summarized in Table 3.

Information gained from treatment of Lower Lake water indicated that the best treatment occurred with approximately 70 parts of iron (in the form of FeCl₃) added per one part arsenic in the untreated solution. It was quickly discovered that addition of this quantity of iron to water from well DH-17 produced an unmanageable volume of precipitant.

TABLE 1. DH-17 WATER QUALITY

PARAMETER	CONCENTRATION (mg/L)
Arsenic	112
Cadmium	<0.005
Copper	<0.005
Iron	5.5
Lead	<0.005
Manganese	8.6
Zinc	2.1

Sample collected January 18, 1990. Analysis performed by DOES laboratory.

TABLE 2. ASARCO EAST HELENA

JANUARY 1990 GROUNDWATER TREATABILITY TESTING

REAGENT	DOSAGES ADDED mg/L					
Beaker #	#1	#2	#3	#4	#5	#6
Clorox	10,000	10,000 1	0,000 1	10,000	10,000 1	0,000
Sodium Hypochlorite (in Clorox)	525	525	525	525	525	525
FeCl ₃	0	400	800	1600	3200	4800
Fe (in FeCl ₃)	0	137.5	275	550	1100	1650
$Mg(OH)_2$	1175	588	1175	1763	2938	4113
PERCOL 710	5	5	5	5	5	5
Initial Eh (mV)	-120	-120	-120	-120	-120	-120
Final Eh (mV)	+690	+660	+670	+680	+680	+620
Initial pH	6.7	6.7	6.7	6.7	6.7	6.7
Final pH	7.7	8.2	8.55	9.0	9.0	9.0

TABLE 3. WATER QUALITY AFTER TREATMENT

<u>PARAMETER</u>		CONCENTRATION (mg/L)						
Arsenic	91.	5.2	0.99	0.37	0.050	<0.020		
Cadmium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005		
Copper	0.013	0.014	0.014	0.017	0.017	0.018		
Iron	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030		
Lead	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005		
Manganese	0.020	0.016	<0.015	<0.015	<0.015	<0.015		
Zinc	0.070	0.040	0.040	0.045	0.032	0.030		

Adjustment of redox potential (Eh) prior to addition of iron was then examined. Adjustment was accomplished through the addition of sodium hypochlorite in the form of Clorox bleach. Analytical results (Table 3) indicate arsenic was removed to below laboratory detection limits with approximately 15 parts of iron (in the form of FeCl₃) added per one part of arsenic in the untreated water, after oxidation (Eh adjustment). This also resulted in manageable volumes of precipitant.

Tests of settling characteristics and settled sludge volumes with and without PERCOL 710 showed pronounced differences. With PERCOL 710 a larger, denser, quicker settling floc was attained. Results are shown in Table 4. Treatment with 4800 mg/l ferric chloride yielded 125 ml of precipitant per liter of groundwater. This sludge could be dewatered with a vacuum filter.

CONCLUSION:

Arsenic and trace metals removal from groundwater by chemical coprecipitation with iron has been shown effective in the laboratory. The treatment process included the addition of sodium hypochlorite, ferric chloride, magnesium hydroxide and PERCOL 710 and filtering through a 0.45 micron filter. Arsenic levels were reduced from 112 mg/l before treatment to <0.020 mg/l after treatment. Treatment resulted in the production of 125 ml of sludge per liter of water treated. Further laboratory testing will be necessary to find the optimum values for chemical addition and optimum contact times.

TABLE 4. SETTLING TESTS

SETTLING PRIOR TO PERCOL 710 ADDITION

SETTLING TIME*	SETTLED VOLUME					
Beaker #						
1 min.				400	380	380
1.5 min.			350	350	350	350
2 min.			300	325	325	300
3 min.			275	275	250	250
4 min.			100	200	175	150
5 min.		50	75	150	50	75

SETTLING AFTER PERCOL 710 ADDITION

SETTLING TIME*	SETTLED VOLUME					
T=0						
0.5 min.		300	300	200	275	300
1.0 min.	~ ~ -	50	100	100	150	200
1.5 min.	Done	40	75	75	75	80
3 min.		40	50	60	50	60
4 min.		30	50	50	50	50

^{*}Slow mix turned off at T=0 min.

⁻ indicates no distinct separation.

APPENDIX 11-3-2

METHODOLOGY AND RESULTS OF FIELD TESTING OF EAST HELENA SOILS WITH ELEVATED METALS

INTRODUCTION

Historic emissions from the East Helena smelter have resulted in elevated metal concentrations and lowered pH values in the agricultural soils to the east of the plant site. As a result, an area of approximately 200 acres is nearly bare of vegetation. Its susceptability to wind erosion makes this area a potential source of fugitive dust, which in turn could disperse metals over a much wider region.

The goal of remediating these soils is to stabilize them against wind and water erosion, and to inhibit metal transport togroundwater by infiltrating precipitation. Early in the FS process it was determined that soil treatment techniques that resulted in the establishment of a healthy vegetative cover could accomplish effective remediation, and should be examined. Three types of treatment were considered for field testing (Hydrometrics and Weston, 1989). One, deep tilling, was tested in the field, and the results are reported herein. A second type of treatment was dropped from consideration after initial investigations, and a third is still under consideration for field testing.

Shallow soil tilling using conventional agricultural implements was considered as a remedial technique, but was ruled out before field testing. Shallow tilling was originally considered for several reasons. The vertical concentration gradients of metals and pH in the soils to be remediated are very pronounced, so that even shallow tillage, to a depth of 6-8 inches, should have some benefits through mixing and dilution. Conventional plows are readily available and relatively inexpensive. Finally, two dryland wheat fields that abut the area under consideration have been under conventional cultivation in recent years, and appear to be in good condition. However, investigations into the capabilities of conventional plows and a discussion with a local farmer (Paul Kleffner) familiar with the soils within the proposed test area indicated that these soils are too rocky for treatment by conventional implements such as a moldboard plow. Therefore, shallow tilling was not tested, however, it can not be ruled out for soils which are deeper and less rocky.

Another treatment method considered for testing in the fields east of the plant was spreading of imported soils. Waste soils from remedial actions involving residential excavations would be brought to the area to be remediated and spread over the ground surface. The application of relatively fertile, rock free, soil onto the unfertile, rocky, eroded soils east of the plant could actually enhance the reclamation potential of these areas. Reclamation techniques such as tillage, and liming and/or fertilization could be part of this treatment. Remediation would be effected by establishing a plant cover in the neutralized surface layer. This treatment method has not yet been tested at the site, however, it has not been dropped from consideration and has been made a part of the Feasibility Study.

The agricultural soils east of the smelter have been examined by soil scientists from the US Soil Conservation Service and, more recently, from Asarco and its contractors. Two general profiles have been described. In one, a shallow soil layer (less than 8 inches deep) overlies a gravelly subsoil. In the other there is an 8-20 inch layer of silty loess atop the gravel horizon, and the lower portion of the loess is strongly enriched with CaCO₃. For these deeper soils, a treatment of deep tilling and planting of a forage cover crop was identified as a promising method of remediation. In deep tilling the soil is mixed to a depth as great as four feet. This dilutes the concentrated surficial metals throughout a deeper layer and mixes the natural lime upward, raising the soil pH, and diminishing both the mobility of metals in the vadose zone and their availability to plant roots.

A test plot was deep tilled in 1988 and various seed mixes were planted on tilled and control areas in 1989. The changes in soil chemistry resulting from the tilling are detailed in this report. Preliminary results from the seeding trials are also discussed.

The objectives of the deep-till treatability test were to:

- o design, field test and evaluate the response of potential remedial alternatives for mitigation of human health and environmental impacts from metal-enriched surface soils using tillage/mixing and revegetation techniques;
- o provide sufficient data to allow the deep soil tillage treatment to be fully developed and evaluated during the Asarco Feasibility Study and to support the Record of Decision; and
- o reduce cost and performance uncertainties for soil treatment alternatives to acceptable levels so that a remedy can be selected.

STUDY METHODS

Field Activities

Based on previous soil surveys, an area just east of the plant site was chosen for the deep-till tests (Figure 1). In November 1988, this entire 600×600 foot area was tested by making small excavations at 60-foot intervals in a regular grid. At each excavation the depth to the CaCO_3 layer and to the gravel subsoil was determined. This information was plotted by a computer isopach mapping program. Based on this map, four test plots at locations of equal soil depth (16-22 inches) were then laid out in the field. Each 100×100 foot plot was divided into equal 50×100 foot tillage and control plots; the designation of the plots to be tilled was randomized.

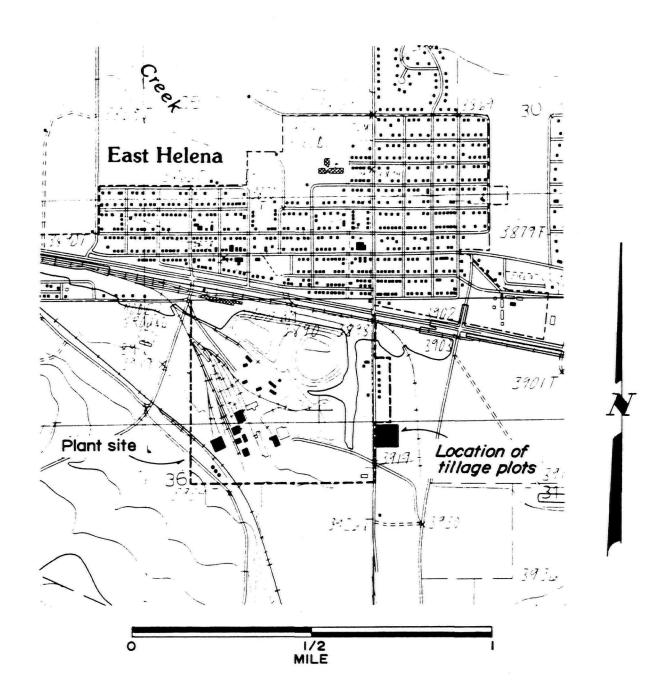


Figure 1. Location of the deep till treatability test plots.

On November 17, 1988 pre-tillage soil samples were collected from the four tillage plots. At each plot four three-foot-deep pits were dug. These pits were evenly spaced along the 100-foot plot centerline. The pits were dug with a small backhoe. One pit wall was cleaned, then sampled with a plastic trowel over the depth intervals 0-4 inches, 4-8 inches, 8-15 inches, and 15-24 inches. When all four pits in a plot had been sampled, samples from the same depth intervals from the four pits were composited by rolling the material on a plastic sheet. Thus each of the four plots yielded four composite samples, one from each depth interval.

After sample collection, the four tillage plots were plowed. The implement used was a custom DIKA Alberta deep plow pulled by a D8 Caterpillar tractor. The ground was tilled in one pass; experimentation adjacent to the plots had indicated that this was sufficient to turn the soil and mix the carbonate layer into the overlying material. The tillage depth was 24-30 inches. After deep-plowing the tillage plots were fertilized with phosphorus (200 lbs per acre of 0-45-0 triple super phosphate) to correct potential nutrient deficiencies due to mixing of the carbonate layer. Plots were chisel-plowed to incorporate the fertilizer and to smooth the soil surface.

To allow the soil to settle from the tillage, further soil sampling was not performed until April 1989. At that time post-treatment composite samples were collected from the four tilled plots. The methods were exactly those used previously, except that the excavations were made at somewhat different locations from those of the previous fall, to preclude an influence from the earlier excavations.

In May 1989 the control (untilled) plots were fertilized with phosphorus as the tillage plots had been the previous fall. All plots were then fertilized with 30 lbs per acre nitrogen (as ammonium nitrate), chiseled and packed to provide a suitable seedbed. Six forage treatments were applied to randomly-assigned 50 x 16 foot subplots in both the control and the tilled plots. The species planted are listed in Table 1. They were selected in consultation with the Lewis and Clark County SCS District Conservationist, the Montana SCS Forage Specialist, and through review of forage studies on metal-affected soils near Anaconda, Montana. The seeds were hand-broadcast at a rate to provide roughly 50 seeds per square foot. The plots were then rolled and mulched with 2000 lbs per acre of straw, which was crimped into the soil.

In August 1989 a preliminary field evaluation of the seeded plots was made. The purpose was to determine general vegetative conditions and estimate the germination rates of the planted species. The vegetative conditions noted included species present (both weeds and planted species), percent vegetative cover and plant vigor. Germination estimates were made by counting seedlings in three locations in each treatment subplot.

Table 1. Species seeded on the Asarco East Helena deep tillage treatability plots.

Trea	tment Common Name	Variety	Latin Name
A B C D E F	Crested wheatgrass Thickspike wheatgrass Pubescent wheatgrass Bluebunch wheatgrass Streambank wheatgrass Forage mix Alfalfa Yellow sweetclover Basin wildrye Streambank wheatgrass Needle-and-thread	Ephraim Critana Greenleaf Secor Sodar Ladak 65 common Magnar Sodar common	Agropyron cristatum Agropyron dasystachyum Agropyron trichophorum Agropyron spicatum Agropyron riparium Medicago sativa Melilotus officinalis Elymus cinereus Agropyron riparium Stipa comata

Soil Analyses and Data Handling

Each composite soil sample was split in the field. One portion was placed in a plastic-lined soil-sample bag, the other in a precleaned ICHEM jar. The bagged samples were used for determination of soil pH by the saturated-paste method (USDA, 1954). These tests were done by Weston in Bozeman. The other samples were dispatched by overnight courier to Asarco's laboratory in Salt Lake City. There they were analyzed for total lead, cadmium, zinc and arsenic. Digestion was by nitric acid and hydrogen peroxide. Analysis was by ICAP (Pb, Cd, Zn) and hydride generation AA (As). All laboratory methods followed the Laboratory Analytical Protocol for the RI/FS (Robbins, 1987).

The Phase I RI Quality Assurance Project Plan (EPA, 1985) was the basis for the QA/QC aspects of the deep-till study. Standard sample-custody and document-control protocols were followed. Validation of soil-chemistry data was based on laboratory measures of data quality (as set forth in the LAP and by Neuman, 1987), and on the following field samples:

natural samples	32
bottle blanks	2
cross-contamination blanks	2
blind field standards	3
field duplicates	6.

Data quality was examined and discussed in a Data Validation report for the treatability study (Weston, 1989). The data were judged to be of good quality; no values were flagged as outliers or estimates.

RESULTS AND DISCUSSION

Soil Chemistry

Figure 2 shows average soil pH profiles before and after deep tilling. The soil pH gradient before tilling was very sharp, with hydrogen-ion content diminishing by four orders of magnitude from the soil surface to a depth of 20 inches. After tilling, soil pH was much more uniform, varying only from 6.6 to 7.6 in the uppermost 20 inches. The tilling appears to have succeeded in mixing the $CaCO_{3}$ upward through the shallow soil.

Soil chemistry data are shown in Table 2, and vertical concentration profiles are plotted in Figures 3-6. For each depth interval, metal concentrations varied considerably among the four test plots. Nonetheless, several trends are clear. Before tilling the soil profiles exhibited very pronounced vertical concentration gradients. The concentrations of As, Cd, Pb and Zn in the shallowest samples (0-4 inches) averaged more than 10 times those in the deepest samples (15-24 inches). Tilling diminished these gradients, depleting metal concentrations above about 6 inches and increasing concentrations below that depth. Table 3 summarizes a comparison of pre- and post-tilling conditions in each depth increment, made by a randomized complete-block analysis of variance (ANOVA). At a probability level of five percent, the ANOVA confirms that metal levels were significantly enhanced at the deepest level sampled and significantly depleted in the surficial materials (0-4 inches). Between those depths metal concentrations were generally not changed significantly.

The data indicate that vertical concentration gradients persisted after tilling. For the four metals tested, levels in the 0-4 inch increment averaged 3.6 times higher than those in the 15-24 inch increment. This suggests that the beneficial effects observed in these trials could be enhanced by making two passes of the plow.

Weighted average metal levels calculated for the pre- and posttilling conditions indicate that the metals of interest increased in the profile as a whole. Calculated increases were: As (46%), Pb (47%), Cd (34%), and Zn (22%). There is no known mechanism by which the tillage could have incorporated external metals into the soil profiles. Three factors may account for the apparent increases. It may be that the tilled soils had not settled completely by the second time they were sampled. If a 24-inch depth of soil were fluffed up to 30 inches, then the top 24 inches were sampled, the lowest-concentration soils (i.e. the deepest ones) would be left out of the samples, and results would be skewed towards higher concentrations. Alternatively, changes in soil chemistry may have enhanced the effectiveness of the sample-digestion procedure in the analytical laboratory. The tilling altered soil pH so much that the chemical forms of the

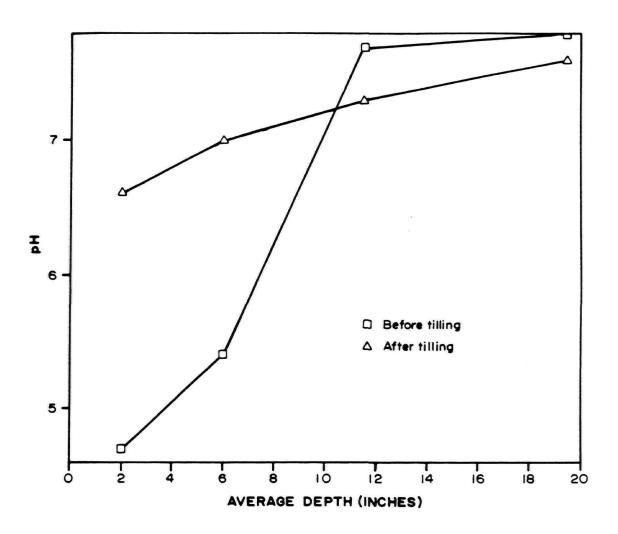


Figure 2. Soil pH (saturated paste) before and after deep tillage.

Table 2. Soil chemical data from the Asarco East Helena deep tillage demonstration plots.

Plot	Depth	Paste	Total	concentr	ration (mg/	kg)
Number	(inches)	pH	Pb	As	Cd	Zn
		Befor	∽e Deep Til	ling		
1	0-4	4.7	3875	348	69	1128
	4-8	4.8	983	141	34	615
	8-15	7.6	13 0	38	22	310
	15-24	8.0	45	18	1.3	140
2	0-4	6.3	3975	390	87	1315
	4-8	7.4	928	134	39	565
	8-15	7.7	1 0 9	30	5.2	130
	15-24	7.8	45	12	0.60	81
3	0-4	4.4	4375	318	85	1225
	4-8	7.3	720	84	28	410
	8-15	7.7	239	33	19	278
	15-24	7.8	12	15	3.6	68
4	0-4	4.9	4625	433	79	1168
	4-8	6.1	1198	148	68	850
	8-15	7.7	160	34	19	263
	15-24	7.8	175	28	3.1	105
		Afte	er Deep Til	ling		
1	0-4	6.4	2975	270	47	903
	4-8	6.9	1795	170	59	1063
	8-15	7.4	980	95	31	495
	15-24	7.5	633	60	12	263
2	0-4	7.0	2488	249	68	958
	4-8	7.2	98 0	150	26	408
	8-15	7.2	1355	146	31	488
	15-24	7.7	11 0 5	129	29	433
3	0-4	6.8	2090	216	49	763
	4-8	7.4	1690	179	39	613
	8-15	7.6	408	63	9.5	196
	15-24	7.6	121	23	1.9	101
4	0-4	6.6	2950	278	75	993
	4-8	6.7	3225	303	71	948
	8-15	7.2	1815	216	41	518
	15-24	7.5	808	104	16	288

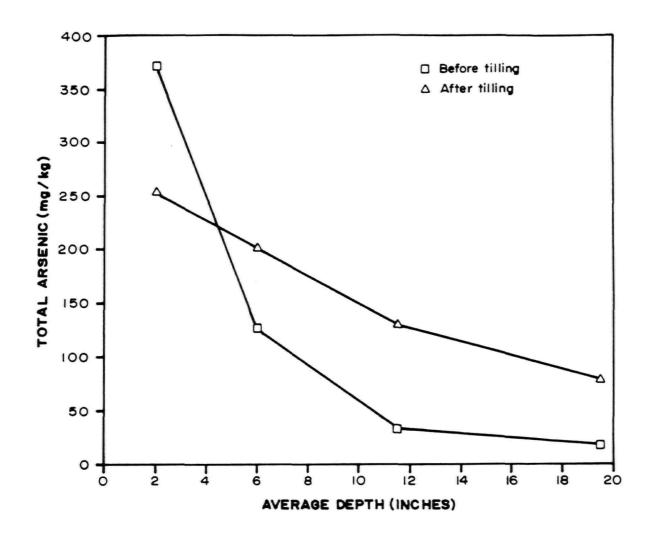


Figure 3. Soil total arsenic concentrations before and after deep tilling.

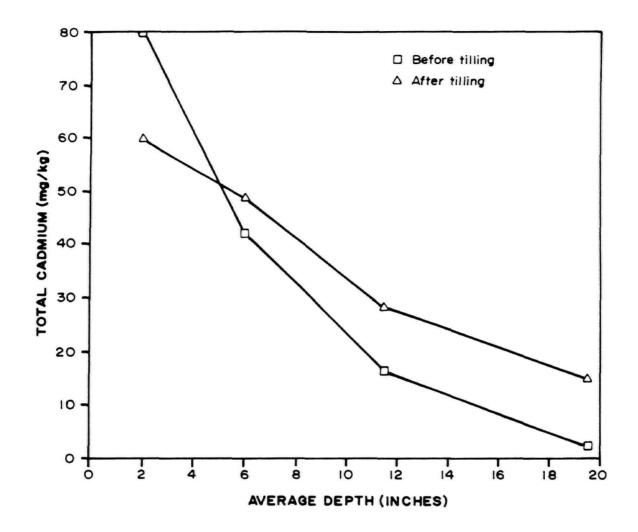


Figure 4. Soil total cadmium concentrations before and after deep tilling.

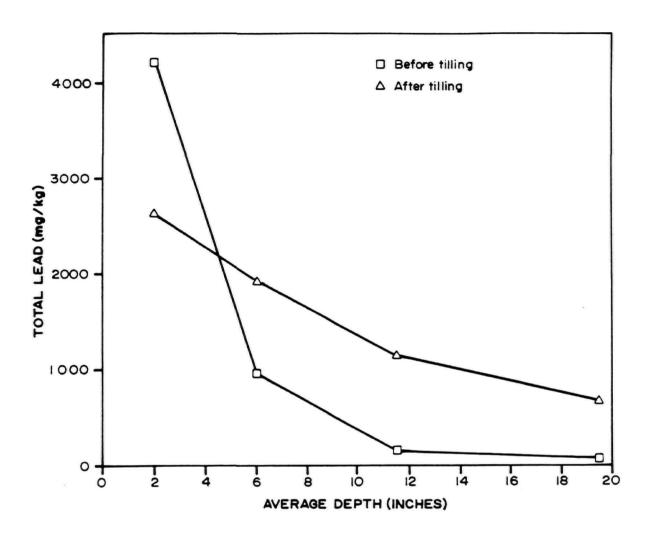


Figure 5. Soil total lead concentrations before and after deep tilling.

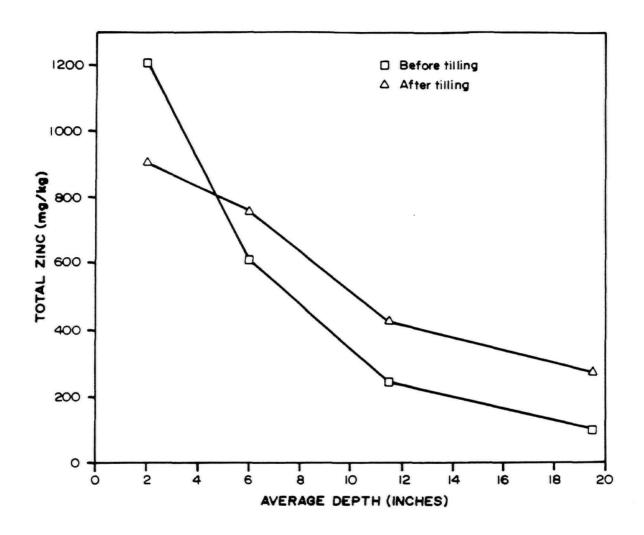


Figure 6. Soil total zinc concentrations before and after deep tilling.

Table 3. ANOVA comparing pre- and post-tilling soil chemistry.

			Aver			
Depth			-Total met	al (mg/kg)		
(in.)	Treatment	As	Cd	РЬ	Zn	рН
0 -4	Untilled Tilled F* Pb	372 253 17.3 0.006	80 60 6.35 0.045	4213 2626 33.6 0.001	1209 904 22.1 0.003	5.1 6.7 13.6 0.010
4-8	Untilled Tilled F*	127 201 3.84 0.098	42 49 0.23 0.645	957 1923 4.03 0.091	610 758 0.71 0.433	6.4 7.05 1.07 0.341
8-15	Untilled Tilled F [®] P ^b	34 130 8.30 0.028	16 28 2.4 0.172	160 1140 10.7 0.017	245 424 4.33 0.082	7.7 7.35 10.8 0.017
15-24	Untilled Tilled F* Pb	18.3 79 6.54 0.043	2.2 14.7 4.95 0.068	69 667 8.13 0.029	99 271 6.12 0.0 48	7.85 7.55 15.8 0.007

a. F value for the ANOVA

b. Probability of an effect excluding random events. P(0.05 is considered significant.

metals may have changed. It may be that the forms present in the higher-pH samples were more readily extracted by the $H_{\rm e}O_{\rm e}/HNO_{\rm s}$ method. Finally, there may have been bias in the sampling: all post-treatment samples may have been collected from what had been a ridge or a furrow. Since the tilling did not provide complete mixing, such bias is theoretical possible. Regardless of the absolute metal concentrations present, successful remediation will depend on stabilizing the metals against wind and water transport and plant uptake.

Vegetation Response

The vegetative condition of the plots was evaluated three months after they were seeded. As expected for the first season, perennial weeds and grasses had a much better start on the treated (tilled) plots than did the planted species. percentage total vegetative cover on all plots (including unplanted species) is shown on Figure 7. The percentages recorded were principally for weeds and unplanted grasses. Planted grasses did not make a significant contribution to overall cover due to their general immaturity. Predominant weed species included wild sunflower, milkweed, bindweed, russian thistle, canada thistle, domestic oats, and several mustards. The weeds grew almost exclusively on the treated plots except for bindweed. Bindweed was the only weed growing in control plots other than occasional oats, milkweed and sunflower, which all showed very poor vigor. Bindweed represented nearly 100 percent of the cover on control plots. For all treatments, vegetative cover was higher on the treated plots than the adjacent control plots. It appeared that both weeds and planted seedlings were less robust on the control plots than on the tilled plots. observations do not pinpoint the reason for greater vegetative cover on the tilled plots, but the neutralization of soil acidity and the immobilization of soil metals may have contributed to this increased growth.

An attempt was also made to evaluate the germination rates of the planted seedlings. However, the data generated are considered to be of low accuracy, and are not reported herein. Factors that compromised the germination data were:

- Many seedlings had barely emerged. This indicated that germination was still underway, and it was too early to make an estimate of germination success for the season.
- Some plots had thick stands of (unplanted) grasses, making the emergent (planted) seedlings very difficult to find and count.
- o Even within plots, a large range in the success of stand establishment was observed.

Plot 1	Treatment	FM 20%	SW 10%	BW 15%	TW 35×	CW 25%	PW 30×
	Control	SW (5%	BW (5%	PW (5%	FM (5%	TW (5%	CW (5%
Plot 2	Control	BW (5%	T₩ (5%	S₩ (5%	P₩ (5%		FM 20%
FIUL E	Treatment	SW 70%	FM 40×	CW 5%	TW 25%	PW 50%	BW

	Control	CW 60%	FM 65%	BW 30%	TW 7%	SW 25%	PW
Plot 3			 			l —	
it	Treatment	SW 70%	CW 75%	PW 80%	FM 25%	BW 40%	TW 65%
	Control	SW	TW	CM	PW	BW	FM
		20%	10%	20%	(5%	(5%	(5%
Plot 4							
t	Treatment	CW 70×	™ (5%	FM 30×	P₩ 55%	BW 70%	SW 90×

Key to abbreviations:

- BW Bluebunch wheatgrass (Agropyron spicatum var. Secor)
- CW Crested wheatgrass (A. cristatum var. Ephraim)
- FM Forage Mix: Alfalfa (Medicago sativa var. Ladak 65), Yellow sweetclover (Melilotus officinalis), Basin wildrye (Elymus cinereus var. Magnar), Streambank wheatgrass (A. riparium var. Sodar), Needle-and-thread (Stipa comata).
- PW Pubescent wheatgrass (A. tricophorum var. Greenleaf)
- SW Streambank wheatgrass (A. riparium var. Sodar)
- TW Thickspike wheatgrass (A. dasystachyum var. Critana)

Figure 7. First-season vegetative cover on control and deeptilled experimental plots.

It is felt that evaluation of the planted plots in later years (beginning in 1990) will provide more useful information than these early observations. Weeds and unplanted grasses will have subsided, and conditions more indicative of long-term remedial prospects will be in effect.

Summary of Conclusions

The conclusions to be drawn from the deep-till treatability study may be summarized as follows:

- One pass of the deep-till plow, mixing soils to a depth of 24-30 inches, was very effective in neutralizing the acidity in the top 10 inches of the soil profile. This was a result of mixing the natural carbonates in the subsoil with the acidic surface materials.
- The tilling ameliorated the pronounced metal concentration gradient in the shallow soils, decreasing soil metal levels sharply within the 0-6 inch layer and increasing the levels below that depth.
- The vertical mixing of both metals and natural carbonates was incomplete; the need for two passes of the plow is indicated.
- 4. The tilling provided a fertile seedbed for weeds and unplanted grasses, such that first-season vegetative cover on tilled plots was considerably greater than on control plots. This is not necessarily representative of long-term conditions.
- 5. A pre-tillage lime amendment may enhance the neutralization/fixation effect of deep tillage and promote vegetation establishment.

The treatability tests confirm the promise of deep tilling to alter soil characteristics in such a way that soil metals can be effectively stabilized in place. To implement deep tilling over a larger area would require information about two basic characteristics of the soil: soil depth and the presence or absence of the carbonate layer. It would not be difficult or costly to gather this information for the entire 200-acre area of interest.

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APPENDIX 11-3-3 SOIL BENCH SCALE TREATABILITY TESTING RESULTS

Includes:

- a) Soil Treatment Testing by Chemical Fixation
- b) Soil Treatment Testing by Electro-reclamation

SOIL TREATMENT TESTING BY CHEMICAL FIXATION



THORNE ENVIRONMENTAL OF

February 13, 1990

Mr. Robert J. Miller Hydrometrics, Inc. 2727 Airport Road Helena. Montana 59601

Dear Mr. Miller:

The benchscale tests on the three soil samples from the Asarco plant in East Helena have been completed. ICAP scans were done for heavy metals on all three samples. Two of the samples only had high levels of lead, as per Table 1. The remaining sample, designated as OSA-1, had sufficiently high total concentrations of arsenic, cadmium, copper, silver, and zinc to raise concerns about the soluble levels of those metals. The total data are presented in Table 1.

All three samples were treated in such a manner as to insure that the metals of concern would have a high probability of passing the TCLP test. The untreated soil samples were also tested. The effort was entirely successful. The soluble data is presented in Table 2.

I look forward to visiting the site to learn more of the project.

Sincerely,

TOXCO

William McLaughlin

President

WM:lh

cc:

J. Nickel

D. Robbins



TABLE 1
TOTAL CONCENTRATIONS OF HEAVY METALS (mg/kg)

Sample No.

ASARCO No. TOXCO Code No.	OSA-1 II-43A	EFS-1 II-43B	EHRS-1 II-43C
Metal			
Antimony	100	< 0.49	< 0.49
Arsenic	638	62.5	24.2
Barium	< 0.43	109	186
Beryllium	< 0.49	< 0.49	< 0.49
Cadmium	503	71.1	52.5
Chromium	14.3	13.6	14.9
Cobalt	78.4	6.63	4.63
Copper	37,300	816	405
Lead	494	3,930	2,280
Mercury	0.331	17.8	16.9
Molybdenum	0.50	< 0.49	< 0.49
Nickel	54.5	10.7	8.04
Selenium	1.24	0.278	0.415
Silver	920	30.7	5.9
Thallium	< 0.49	< 0.49	< 0.49
Vanadium	1.53	22.5	23.9
Zinc	51,600	1,419	1,348

TABLE 2
SOLUBLE LEVELS OF HEAVY METALS
ASARCO - EAST HELENA

ASARCO Sample No.	TOXCO Code No.	Metal	Soluble Before Treatment*	e Levels (mg After Treatment*	g/l) Normal Limit
OSA-1	II-43A/D	As Cd Cu Pb Ag Zn	<1.25 22.0 3.4 70.0 <0.1 247	< 1.25 < 0.1 < 0.1 < 0.1 < 0.1 0.2	5.0 1.0 5 5 250
EFS-1	II-43B/E	Hg Pb	< 0.005 20.6	<0.005 <0.1	0.2 5
EHRS-1	II-43C/F	Hg Pb	< 0.005 4.8	< 0.005 0.2	0.2 5

^{*} Toxicity Characterist Leaching Procedure Test Data

SOIL TREATMENT TESTING BY ELECTRO-RECLAMATION



Department of Civil Engineering

LOUISIANA STATE UNIVERSITY AND AGRICULTURAL AND MECHANICAL COLLEGE BATON ROUGE · LOUISIANA · 70803-6405

504 / 388-8442

January 25, 1990

Mr. John Steude Electrokinetics, inc. 1929 Crisanto, Suite 1008 Mountain View, CA 94040

Dear John:

We have done some preliminary testing for the soil transmitted from ASARCO East Helena Site. The initial Pb(II) content in this sitty deposit was found to be about 4600 ppm. We have packed this soil in an electro-osmosis cell (2 in. in diameter and 4 in. in length) and applied a current of 0.03 mA/cm². The flow was very low and the voltage was quite low. We removed this specimen in about 10 days of testing. The Pb(II) content was about 4200-4600 ppm with about 10% reduction at the anode region. Subsequently, we increased the water content of the specimen, repacked it in the cell and applied a current of 0.10 mA/cm² and kept the current for about one month. The flow was very low and we had to stop the test due to ongoing other research in our laboratory.

We dissected the specimen into 5 sections and determined the Pb(II) content in each section. The Pb(II) content had decreased by about 20-25% at the anode section, while a 10% decrease was also observed towards the cathode.

The results are very promising as we did not seek all avenues of removing the Pb(II) with electrokinetic soll processing. However, it is necessary to conduct further laboratory tests:

- (1) to assess the repeatability of the results,
- (2)to determine the voltage/current regime to be used for field applications,
- (3)to determine the probable processing period.
- (4) to improve the flow by circulating a solution at the anode and the cathode,

Please call me if you have any questions.

alcin B. Acar, Ph.D., P.E.

Associate Professor

ELECTROKINETICS INC. Electrokinetic Soil Treatment Processing

January 30, 1990

Mr. Kevin Harvey
Office Manager
Roy F. Weston, Inc.
1919 Fairway Drive
Bozeman, Montana 59715

Dear Mr. Harvey:

Enclosed is a summary of the preliminary electrokinetic soil treatment study on the soil sample from the East Helena Site. Considering the limited resources to conduct the treatability experiments, the results are very promising. With the resources to optimize the experiments, it is likely that much more than 25% of the metal contaminants could be separated from the soil.

If you are interested in further exploring the possibilities of electrokinetic soil treatments, please contact me so that we can plan the next step.

Sincerely,

John Steude Project Manager

1929 Crisanto Ave. #1008, Mountain View, CA 94040 (415) 964-4374

APPENDIX 11-5-1

GROUNDWATER MODELING OF PLANT SITE ARSENIC PLUME INVESTIGATION SCENARIOS

APPENDIX 11-5-1

REMEDIAL ACTION GROUNDWATER FLOW AND SOLUTE TRANSPORT MODELING

METHODOLOGY

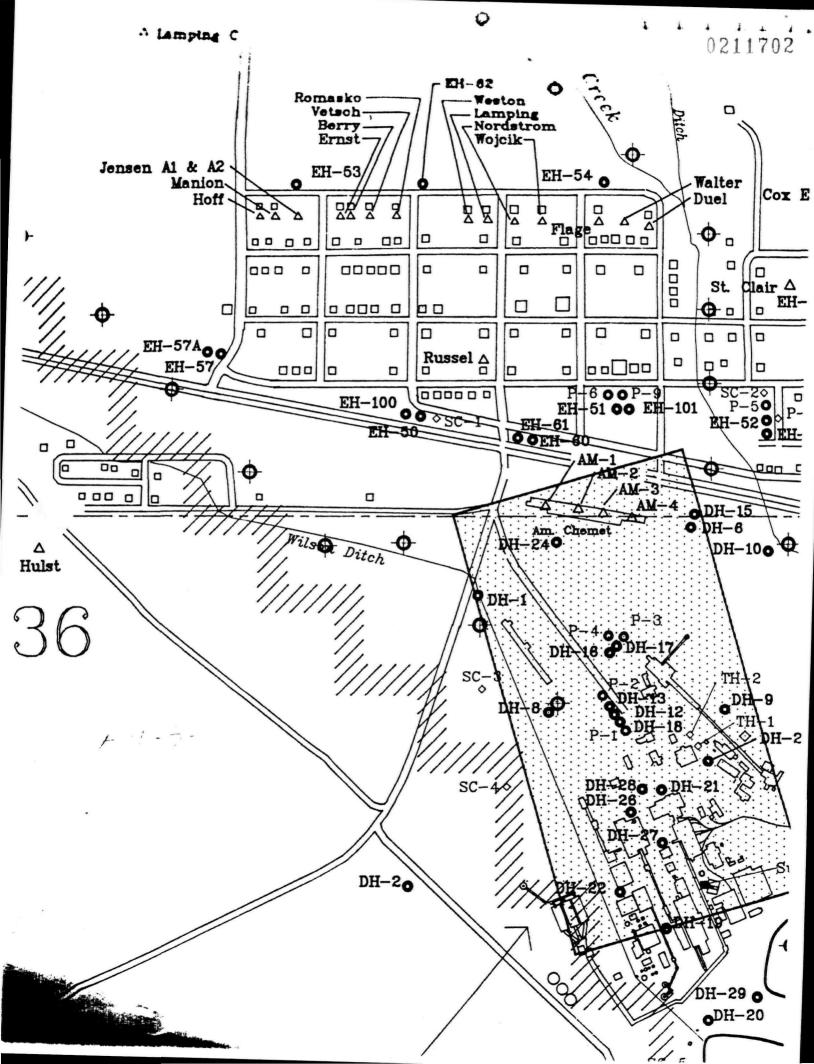
Previous computer modeling efforts simulated the fate and transport of arsenic in groundwater in the shallow aquifer at the East Helena plant site and at East Helena (see Section 8.3.3). These results formed the basis of another model which was used to examine the feasibility of intercepting groundwater with elevated arsenic using extraction wells (Alternative GW-3A or GW-3B). This remedial action model focuses on contaminant movement in the plant site area specifically where the most elevated arsenic concentrations are present.

A steady-state groundwater flow simulation was first used to establish ambient groundwater flow at the plant site area. Several pumping scenarios were then simulated using variable pumping schedules and different well configurations to create capture zones. The pumping scenarios with maximum achievable pumping rates were then used in the solute transport model to examine the feasibility of containing arsenic plume migration to the plant site area.

The computer codes used to model arsenic plume pumping scenarios were PLASM (Prickett and Lonnquist, 1971) and Random-Walk (Prickett and others, 1981). These are the same computer models used in the earlier groundwater flow and solute transport simulations and are discussed in Section 8.3.3.

GROUNDWATER FLOW INPUT PARAMETERS AND MODELING ASSUMPTIONS

The model area is shown in Figure A-11-5-1 and boundary conditions and node locations are shown in Figure A-11-5-2. These data are also presented numerically in a Plasm PLA file in Appendix 11-5-1. The grid in Figure A-11-5-2 is a 15 by 22 grid system with variable node spacings of 75 and 150 feet along the Y-axis direction. Nodal spacing was reduced where simulated recovery wells were placed in the model. This enabled simulated wells to be placed relatively close to each other and provided better detail for determining drawdown effects.



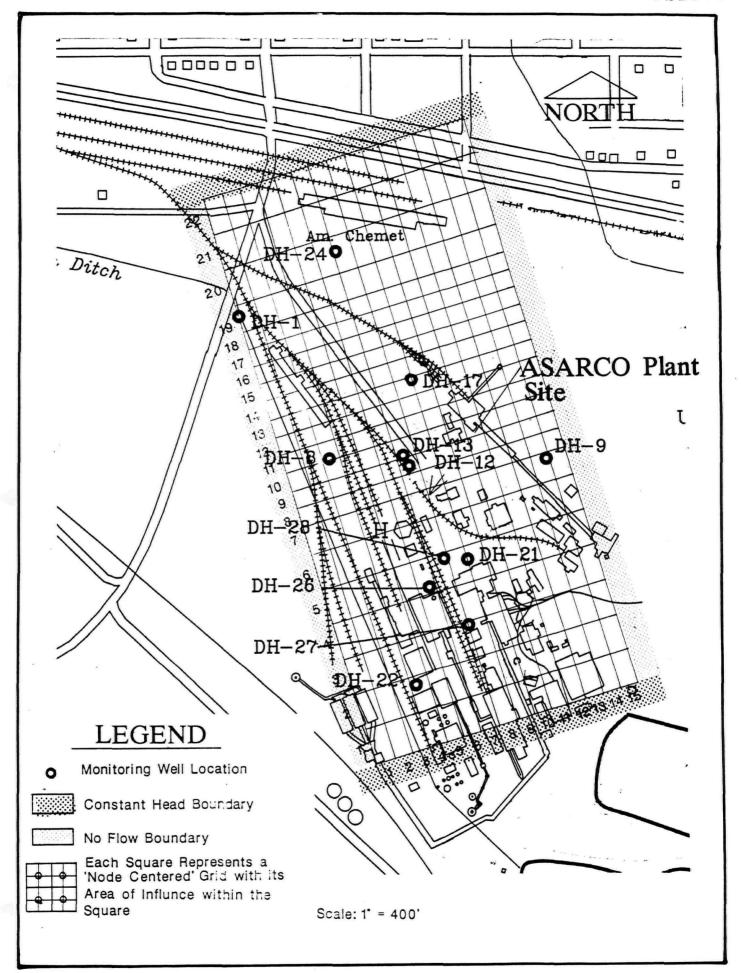


Figure A-11-5-2. Model Boundary Conditions and Node Locations

Input values for aquifer coefficients, including hydraulic conductivity, porosity, storage, and aquifer depth are the same as those used in the groundwater flow model described in Section 8.3.3.2. These input parameters are also presented as Appendix A-1 of this model report.

A cumulative model error tolerance of 2 feet was selected for the remedial action model (an explanation of cumulation model error tolerance is given in Section 8.3.3.2). This value is well within the recommended four feet calculated by the PLASM code for a 15 by 22 grid. A simulated head accuracy of two feet was selected for comparison of actual monitoring well water levels and simulated water levels. A two foot simulated head accuracy is considered sufficient to determine drawdown effects from the groundwater pumpage scenarios (see Section 8.3.3.2).

Seven time steps were used to model steady-state heads for a period of five years. The PLASM water balance was used in the steady-state head simulation to determine the percent of water lost or gained in the modeled input parameters and boundary conditions.

The pumping scenarios consisted of nine different extraction well configurations with three different pumping rates for each configuration. Each pumping rate was simulated for a five year period to produce a "steady-state" groundwater flow field. Typically, seven wells were used in each of the scenarios. Based on pumping simulation results, the four most effective well configurations were selected for plume control simulations in the contaminant transport run.

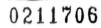
Assumptions used in the pumping simulations are:

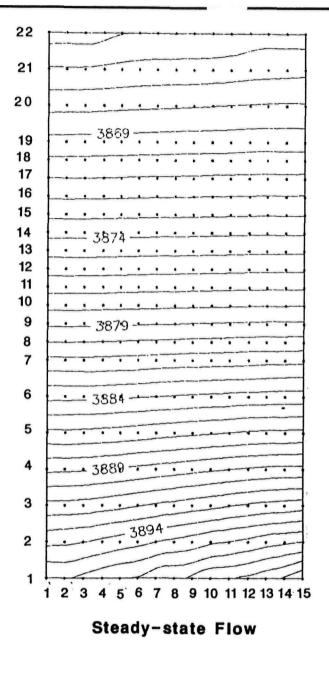
1) The shape of the cone of depression during actual pumping resembles the simulated cone of depression. Actual pumping rates may differ from simulated rates because of the heterogeneous nature of the shallow aquifer in the plant site area. Actual pumping rates may have to be adjusted to compensate for different drawdown rates due to the influence of aquifer heterogeneity and anisotropy.

- The shallow-aquifer dimensions at the plant site are similar to the simulated aquifer dimensions. This would include aquifer depth and boundary locations.
- 3) The simulated recovery wells are 100% efficient.
- 4) The actual groundwater flow direction is not affected by three dimensional heterogeneities in the aquifer and can be simulated in two dimensions, and arsenic plume migration is perpendicular to the potentiometric lines of the shallow aquifer. Actual head data and arsenic concentrations will not always coincide with each other in a two dimensional simulation due to three dimensional heterogeneities.
- 5) With the exception of the pumping well area, the shallow aquifer is at steady-state. Other than effects from actual pumping, changes in flow direction and/or hydraulic head in the shallow aquifer do not occur over the duration of the simulation.
- 6) The simulated aquifer parameters represent average values for the shallow aquifer in the plant area.
- 7) The aquifer bottom is impermeable and no recharge occurs along this area nor is there any surface water recharge. Constant head boundaries provide all available groundwater for the simulations.

GROUNDWATER FLOW MODELING RESULTS OF PUMPING SIMULATIONS

A steady-state groundwater flow field (fall 1987 head data) is shown in Figure A-11-5-3. A regression plot of the actual versus simulated head (Figure A-11-5-4) indicates a good correlation exists. The actual and simulated water level data are shown in Table A-11-5-1. The calculated coefficient of determination (r^2) for the regression plot (0.95) also indicates a good correlation exits between the actual and simulated head data.





Scale: 1' = 400'

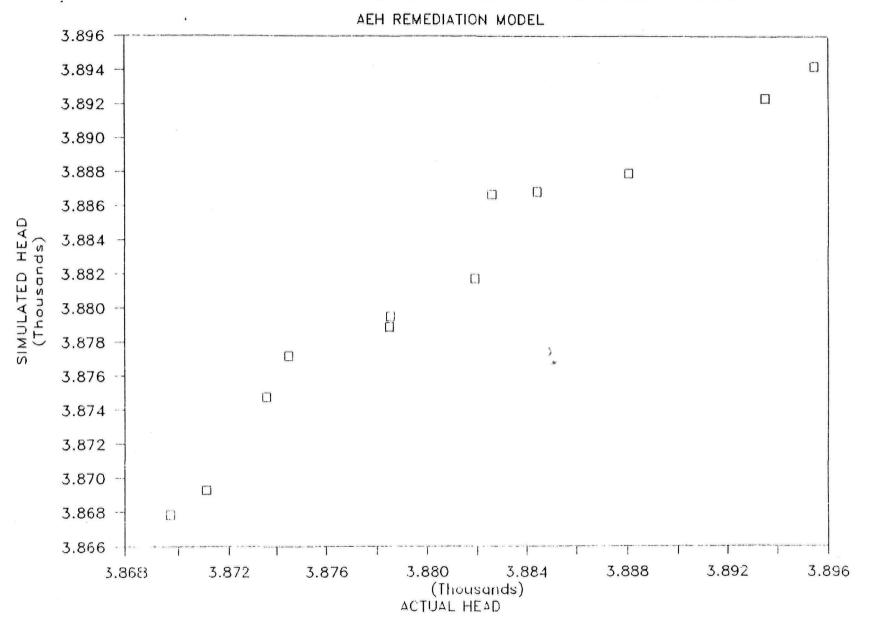


Figure A-11-5-4. Regression Plot of Actual vs.
Simulated Head Data

STEADY-STATE FLOW STATISTICS (FEET)

	ACTUAL WL	SIM WL	DIFF.
MW			
DH-1	3871.11	3869.31	1.8
DH-24	3869.7	3867.85	1.85
DH-8	3874.47	3877.18	-2.71
DH-17	3873.58	3874.76	-1.18
DH-13	3878.49	3878.91	-0.42
DH-12	3878.53	3879.5	-0.97
DH-22	3895.43	3894.22	1.21
DH-26	3888.04	3887.91	0.13
DH-28	3882.57	3886.66	-4.09
DH-21	3884.39	3886.83	-2.44
DH-27	3893.49	3892.36	1.13
DH-9	3881.89	3881.72	0.17

Regression Output:

Constant	0
Std Err of Y Est	1.893715
R Squared	0.949784
No. of Observations	1 2
Degrees of Freedom	11

X Coefficient(s) 1.000118 Std Err of Coef. 0.000140 Actual water level data are summarized in Table A-11-5-1 for twelve monitoring sites. Seventy-five percent of the simulated data are within two feet of the actual head data and within the selected head difference tolerance. This supports the conclusion that the steady state simulation results are relatively close to actual fall 1987 data.

Pumping well locations for the four most effective well configurations are shown in Figures A-11-5-5 through A-11-5-8. Pumping from each recovery well was simulated with rates ranging from 10 to 18.5 gpm. The maximum sustainable simulated pumping rate was 18.5 gpm. The 18.5 gpm pumping rate was selected for contaminant plume control simulations because it is intuitively more effective in controlling arsenic migration than lower pumping rates.

Pumping scenarios A through D (Figures A-11-5-5 through A-11-5-8) show similar drawdown effects from pumpage. However, placement of the wells does have an effect on the cone of depression shape. The best drawdown effects appear to be in scenarios B and D (Figures A-11-5-6 and A-11-5-8, respectively).

SOLUTE TRANSPORT MODELING

Solute transport modeling was conducted to examine the feasibility of groundwater pump and treatment options. Simulated results were used to determine arsenic plume interception and removal efficiency. The sensitivity of the model input variables was also examined.

PLUME INTERCEPTION MODELING INPUT PARAMETERS, MODELING TECHNIQUES, ASSUMPTIONS

Before arsenic migration was modeled using the Random Walk solute transport program, the simulated flow fields were converted into velocity vector fields. The arsenic plume was then modeled to migrate in accordance with the simulated flow data. "Steady-state" conditions were assumed for all flow fields and changes in head were assumed to be negligible for the solute transport simulation.

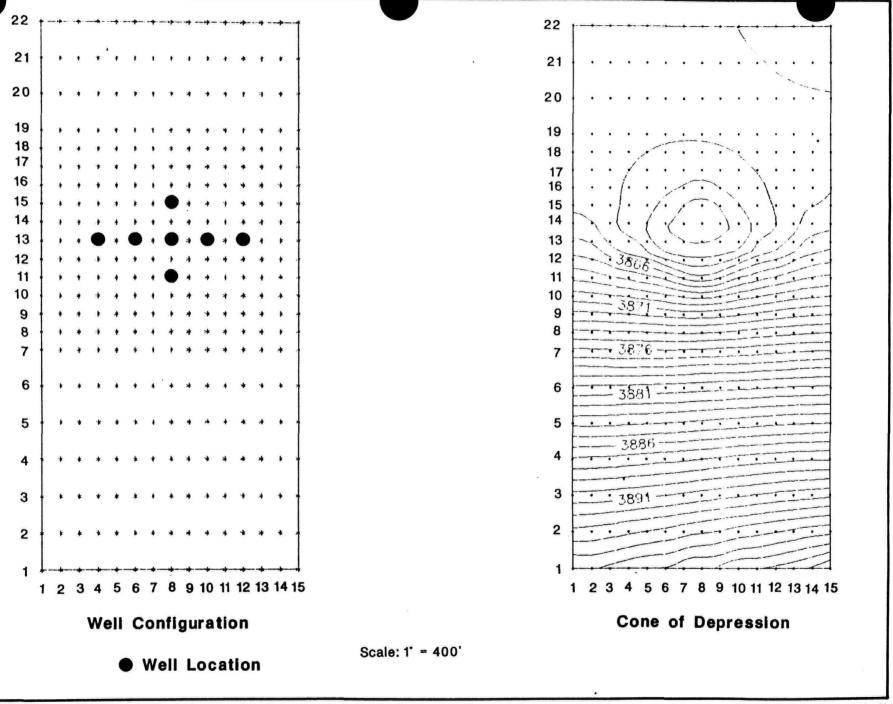


Figure A-11-5-5 Scenario A Well Configuration and Pumping Results (18.5 GPM Pumping Plate All Wells)

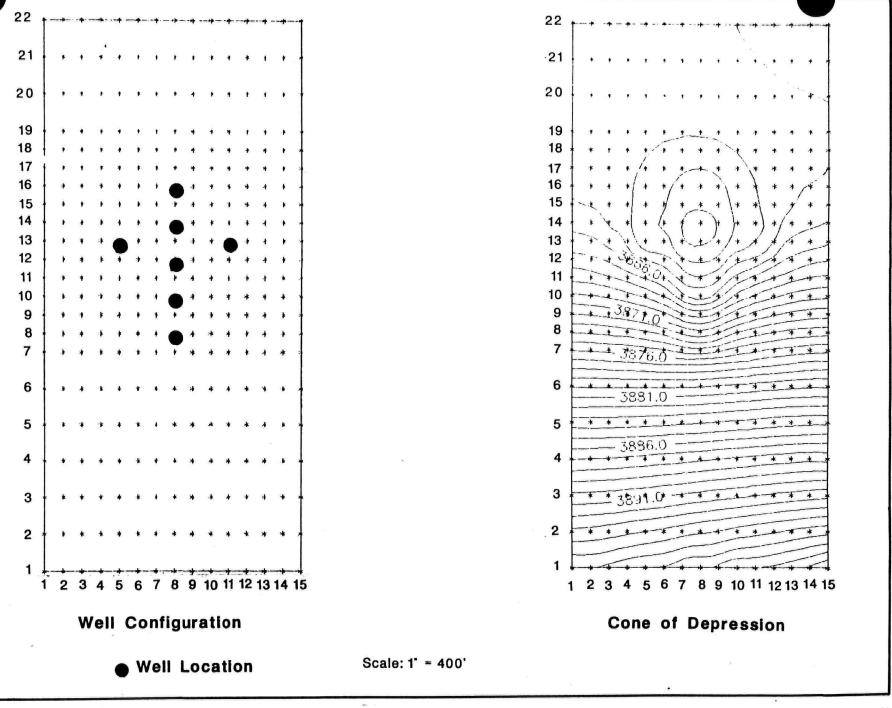


Figure A-11-5-6. Scenario B Well Configuration and Pumping Results

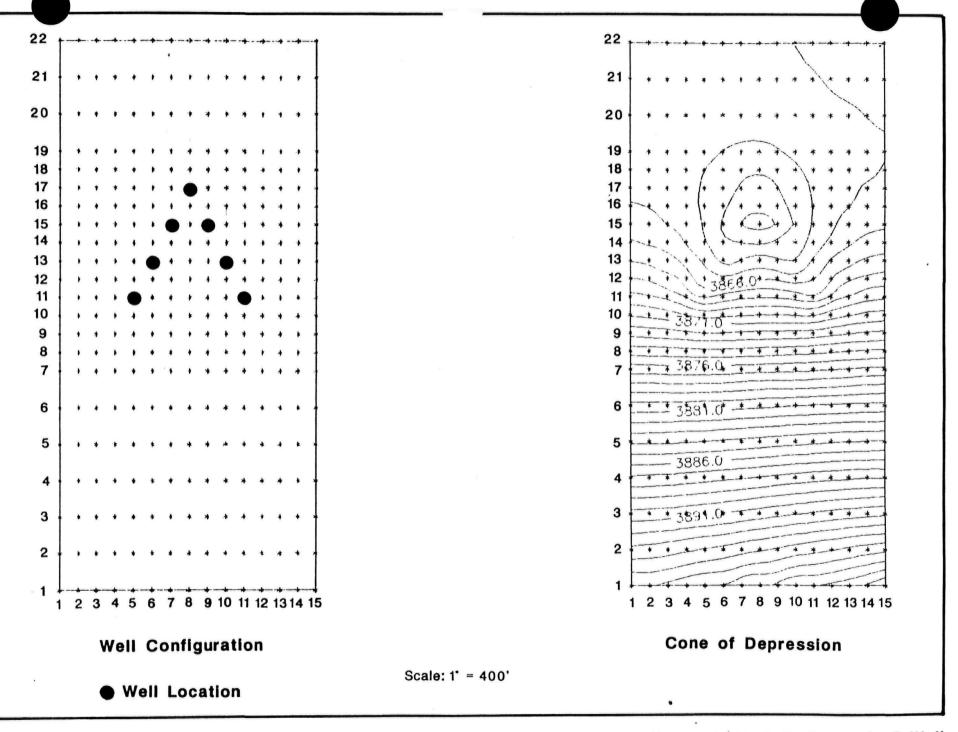


Figure A-11-5-7. Scenario C Well Configuration and Pumping Results

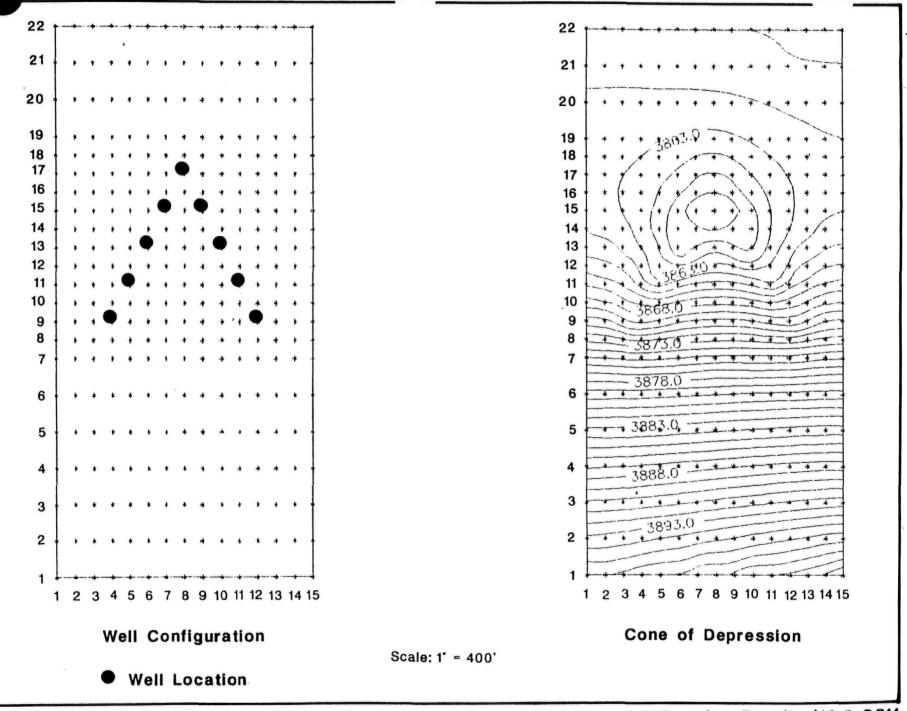


Figure A-11-5-8. Scenario D Well Configuration and Pumping Results (18.5 GPM Pumping Rate All Wells Execpt (4,9) and (12,9) Pumping 15 GPM)

Simulations of arsenic migration during pumping were run assuming arsenic sources at the plant were remediated and no new arsenic was loaded into the groundwater system.

Model input variables were retardation, longitudinal dispersivity, transverse dispersivity, particle mass, porosity, location of contaminant source area and timing of contaminant loading.

The plant site area ambient plume position was modeled to represent the arsenic plume prior to pumping. Previous contaminant fate and transport modeling efforts (Section 8.3.3.4) assumed an arsenic retardation factor of 30 in an attempt to simulate existing plume conditions. However, as described in Section 8.3.2, arsenic is apparently quite mobile in the plant site area, and is more susceptible to removal from the aqueous phase of the aquifer when favorable geochemical conditions are encountered downgradient in the East Helena area. Determination of migration timing was not a goal for this ambient plume position simulation prior to pumping. Therefore, no retardation was used for the ambient (before pumping) plume simulations and arsenic was assumed to move freely with groundwater.

A slight retardation factor of two was used in the pumping simulations. A retardation factor of two was selected because it is thought to approximate limited chemical reactions and physical conditions that affect arsenic migration in the plant site area (see Sections 8.3.1 and 8.3.2). However, since this value was not confirmed in earlier modeling efforts, the timing of arsenic migration during pumping can only be regarded as an approximation.

Dispersivity for the remedial action model was estimated in consideration of dispersivity values used in the previous contaminant fate and transport modeling efforts. Dispersivity values for the contaminant fate and transport model (Section 8.3.3.4) were 300 in the longitudinal direction and 5 in the transverse direction. The best pump interception modeling results were accomplished using a longitudinal dispersivity of 50 and a transverse dispersivity of 2. Other modeling attempts were conducted using dispersivities as high as 200 in the longitudinal direction and 5 in the transverse. Arsenic transport

simulation results using higher dispersity values were somewhat similar to results using lower dispersivity values. However, since dispersivity is scale dependent, values of 50 and 2 probably are more representative since the model area is approximately six times smaller than the previous contaminant fate and transport model.

Arsenic in the plant site area aquifer was simulated as movement of "particles" of arsenic using the Random Walk model. A minimum of 500 particles are required to provide a statistically valid representation of plume migration; however, because of program limitations, the number of particles cannot exceed 1000 (Prickett, 1981). Assigning particle mass of 20 lbs., a total of 630 particles were input to the model to simulate the ambient (before pumping) plume.

The location representing most plant site arsenic loading sources was given as a rectangle with lower left coordinates of $\{5, 2\}$ and upper right coordinates $\{11, 6\}$ (see Figures A-11-5-5 through A-11-5-8). In addition, a smaller rectangle located at lower left coordinates of $\{8, 4\}$ and upper right coordinates $\{10, 5\}$ was used to represent the speiss pond area where arsenic loading is the highest. The timing of particle input was not a concern since no retardation was used to simulate the ambient (before pumping begins) plume.

SOLUTE TRANSPORT MODELING RESULTS

Simulated initial plume conditions before pumping begins are shown in Figure A-11-5-9. A total of 630 particles were input into the model using the methods described above to represent the ambient arsenic plume position. Simulated arsenic concentrations varied from 5 mg/l on the edge of the plume to 229 mg/l in the spiess pond area. Simulated concentrations were higher on the edge of the plume and lower in the speiss pond area than actual plume concentrations. However, the differences in actual versus simulated arsenic concentrations are relatively unimportant since the goal of these modeling efforts was to determine if the arsenic plume could be intercepted and removed using pumping wells. In this model, the particles were sufficient to track arsenic movement.

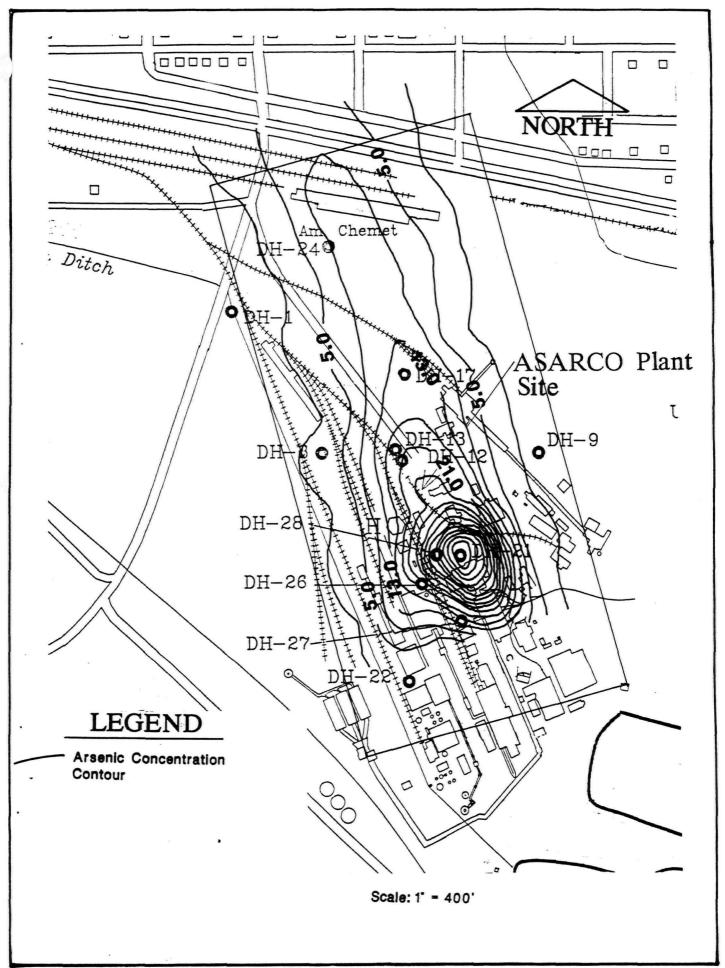


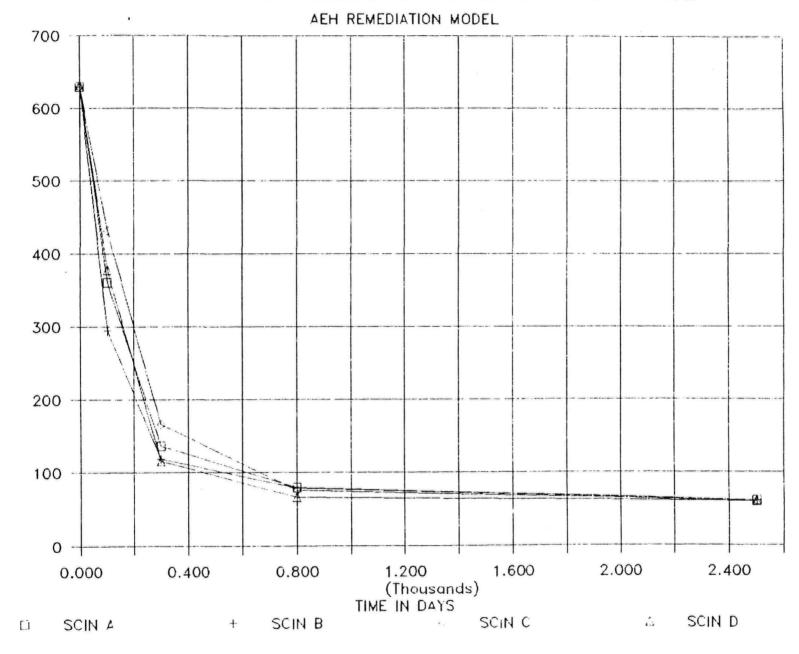
Figure A-11-5-9. Initial Arsenic Concentration in mg/l Prior to Remedial Pumping (Example 1)

Results of the pumping scenarios are presented in Appendix A-2 as photographs A-1 through D-5, and as numerical summaries. The results indicate that simulated pumping intercepted and removed most arsenic within 800 days. Limited residual arsenic was removed over the remainder of the simulation (2500 days). Figure A-11-5-10 summarizes this data graphically and compares particles in groundwater versus time for each of the four well configuration and pumping rate scenarios. Again, it should be noted that actual reduction rates may differ from those projected by the model, although a comparison between well configurations is still valid. Scenario B appears to be the most efficient well configuration (shown on Figure A-11-15-6), removing particles somewhat quicker than the other well pumping configurations. However, all four scenarios are very similar to each other and approximately 60 particles remain at the end of each simulation after 2500 days of movement. Most of the particles that remain were downgradient of the pumping wells prior to initiation of continued to migrate downgradient after pumping began. Removal efficiency of approximately 90% was achieved by all simulated scenarios.

In order to examine the sensitivity of the model, additional simulations were run assuming different ambient (before pumping) plume configurations (see Figure A-11-5-11). The ambient arsenic plume shown in Figure A-11-5-11 is similar to the arsenic plume in Figure A-11-5-9 with the exception that simulated arsenic migration is not as far advanced as in Figure A-11-5-9. Pumping simulations, assuming a less advanced plume, showed interception removal efficiency improved to 99% leaving 7 particles remaining at the end of each 2500 day simulation. Recovery efficiency is somewhat dependent on the plume configuration. Simulations with both ambient (before pumping) plume configurations (Figures A-11-5-9 and A-11-5-11) intercepted arsenic from the source areas to the pumping wells areas. However, some arsenic particles downgradient of the pumping wells were not captured during the pumping simulations.

Another variable that affected simulated arsenic interception and recovery efficiency was dispersivity. Larger dispersivity values (200 in the longitudinal direction and 5 in the transverse) decreased simulated interception and recovery efficiency to approximately 80%. However, the larger dispersivity values were probably too high considering the size of

NO. OF PARTICLES II. THE GW VS. TIME



NO. OF PARTICLES

Figure A-11-5-10. Comparison of Particals in the Groundwater vs.

Time to Remove the Particles for Each Scenario

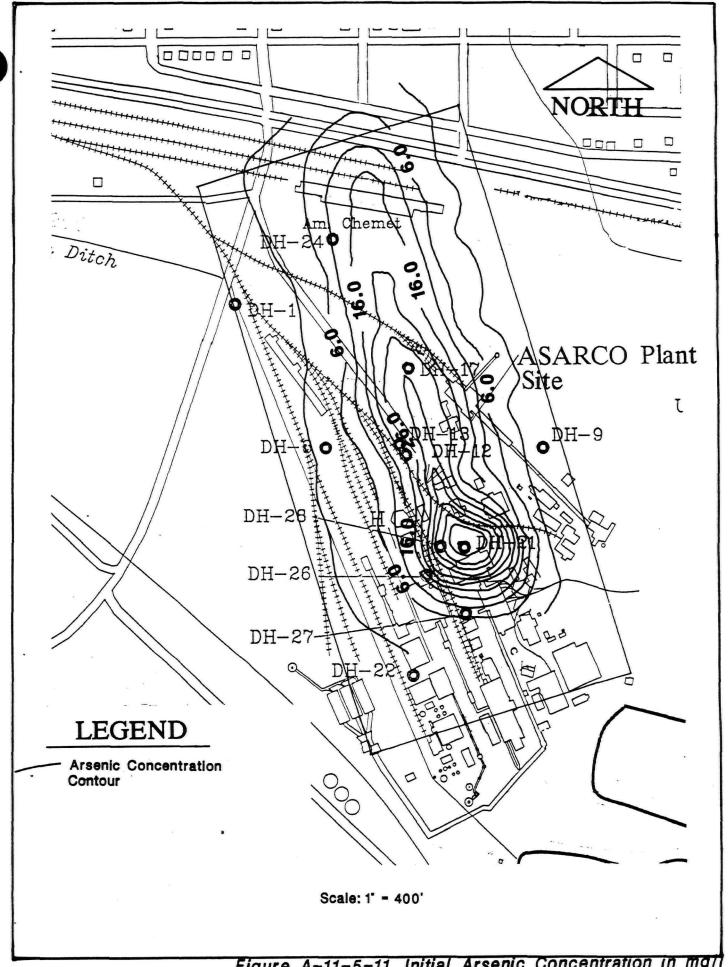


Figure A-11-5-11. Initial Arsenic Concentration in mg/l Prior to Remedial Pumping (Example 2) the model and the smaller values used are probably more representative of actual conditions.

CONCLUSIONS

Results of the solute transport simulation using the modeled flow fields suggests that arsenic plume interception and pumping removal using wells is technically feasible. Installation of about seven wells with overall pumping rates averaging 15 to 18 gpm each will probably intercept 90% of plant site area groundwater with the highest concentration of arsenic northwest of the main plant complex area.

Actual recovery wells installed at the plant site will have to be versatile and be able to alter pumping rates. The actual cone of depression should mimic the simulated cone of depression for interception and removal of arsenic to be successfully implemented. Actual interception and removal efficiency is dependent upon whether the actual system reacts similarly to the simulated system during pumping. Assuming actual pumping rates and aquifer conditions are similar to modeled conditions, arsenic interception and removal should be successful.

APPENDIX A-1
PLASM PLA FILE SCENARIOS A, B, C, D

PLASM PLA FILE SCENARIO A

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PLASM PLA FILE SCENARIO B

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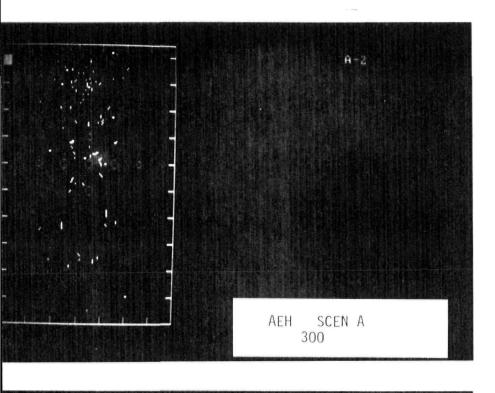
APPENDIX A - 2 REMEDIAL ACTION SOLUTE TRANSPORT RESULTS

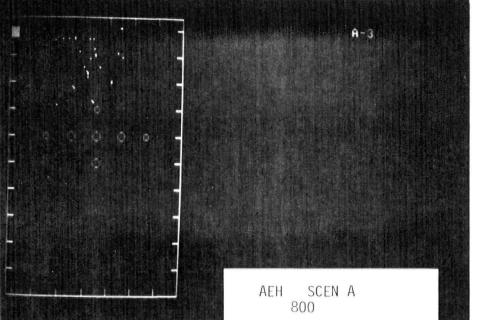
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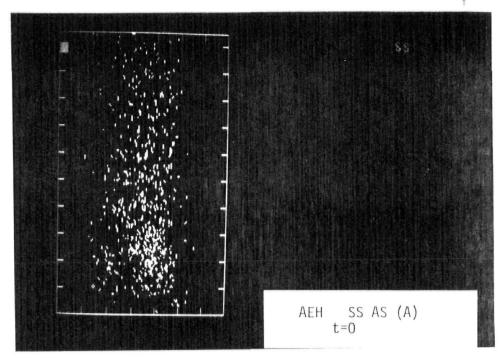
- 1) Scenarios A through D Photography Result (A-1 through D-4)
- 2) Random-Walk Numerical Output

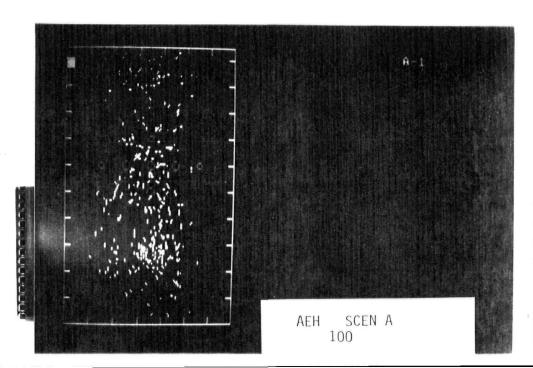
SCENARIO A THROUGH D - PHOTOGRAPHY RESULT

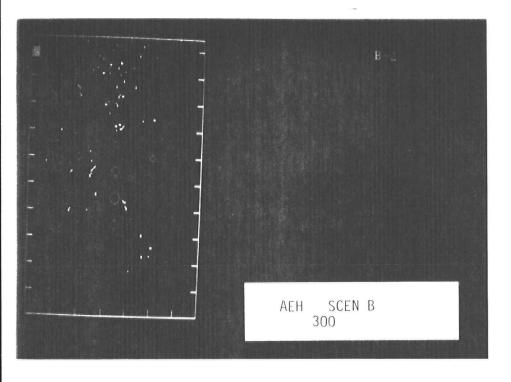
(A-1 THROUGH D-4)

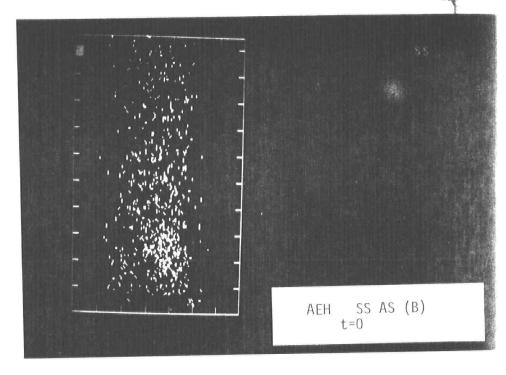


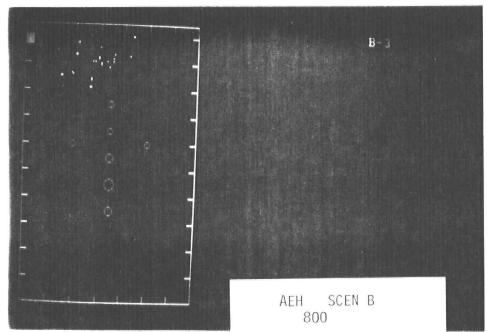


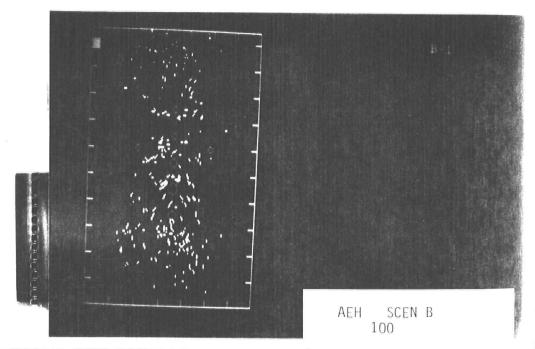


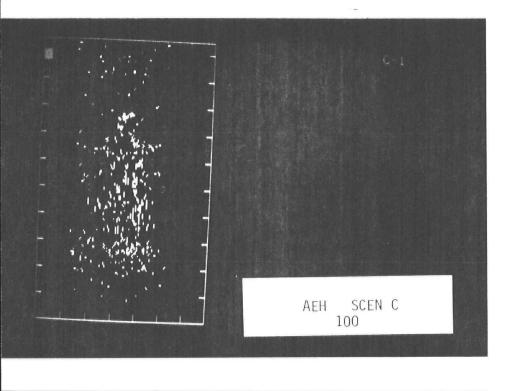


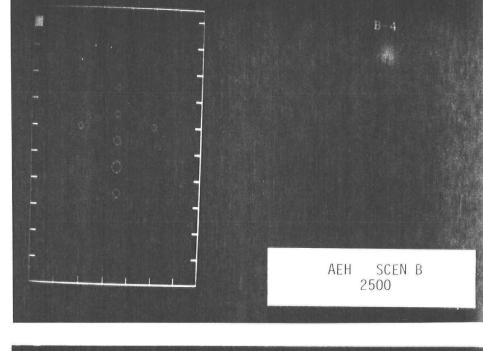


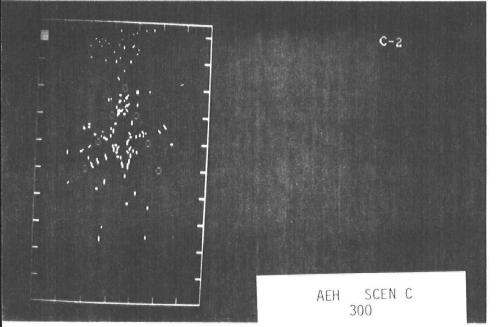


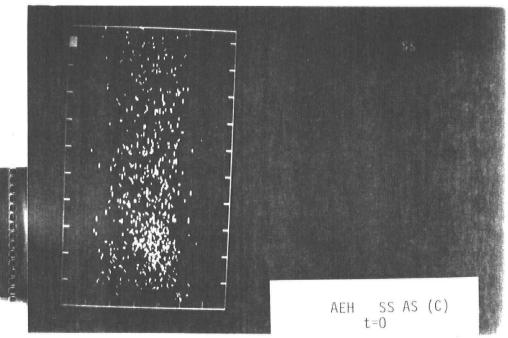


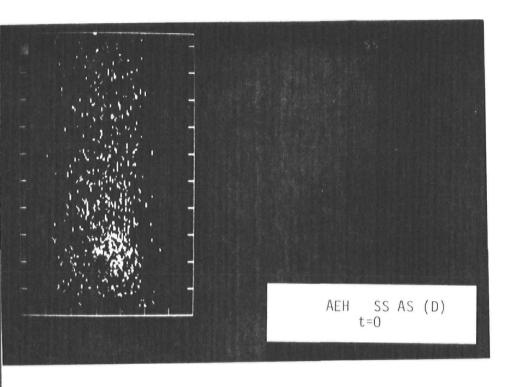


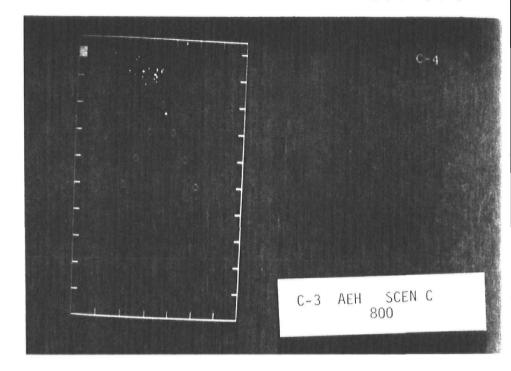


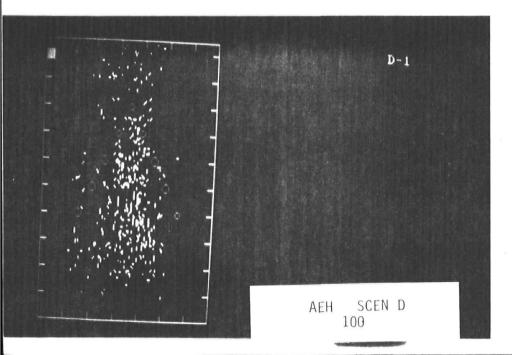


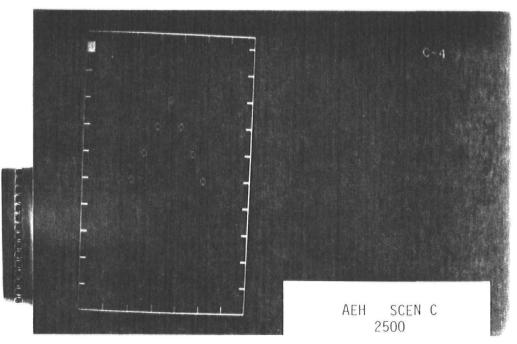


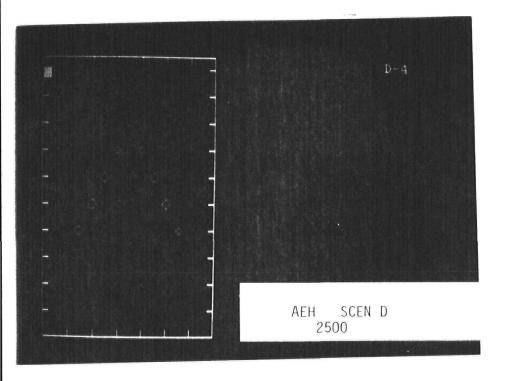


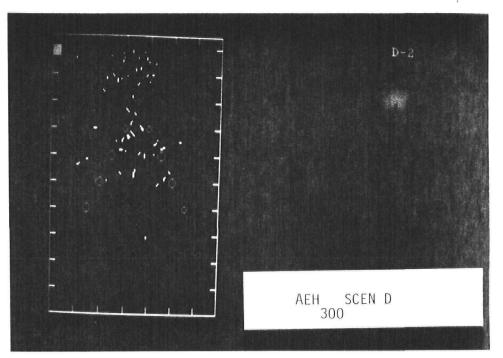


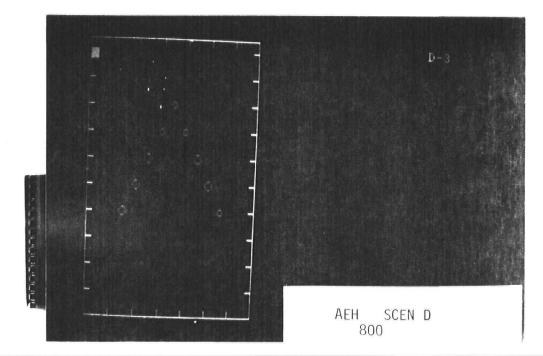


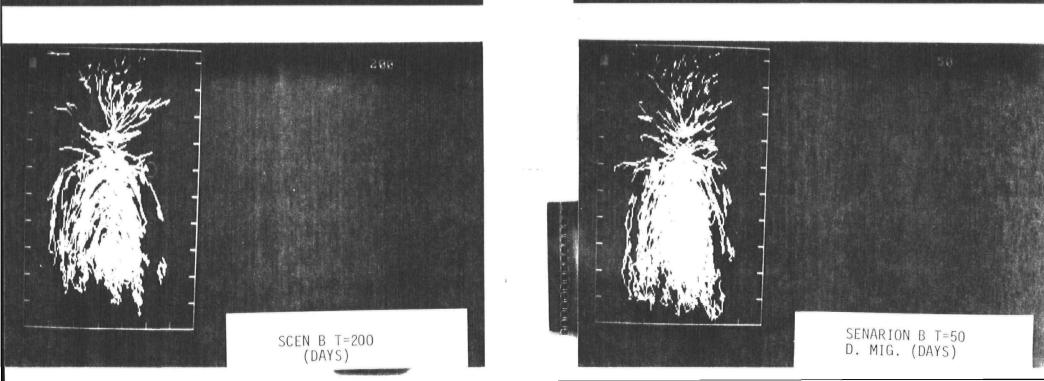




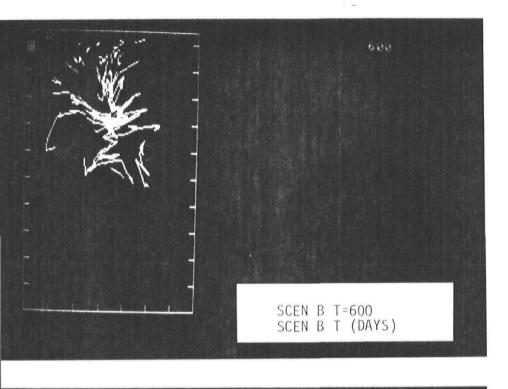


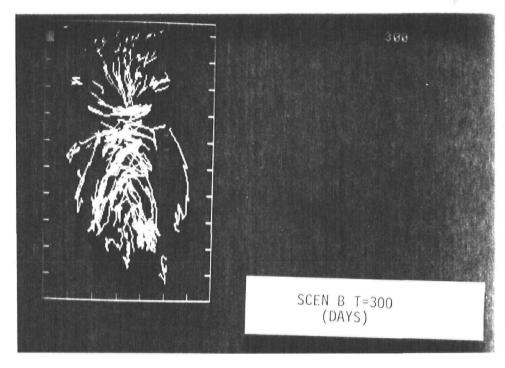


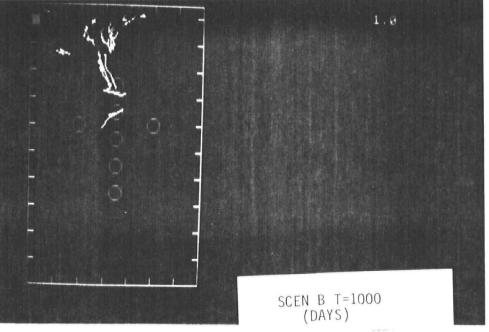


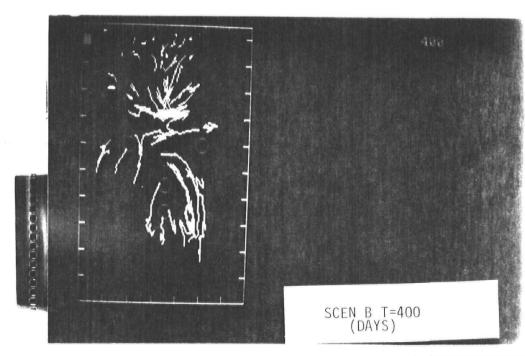


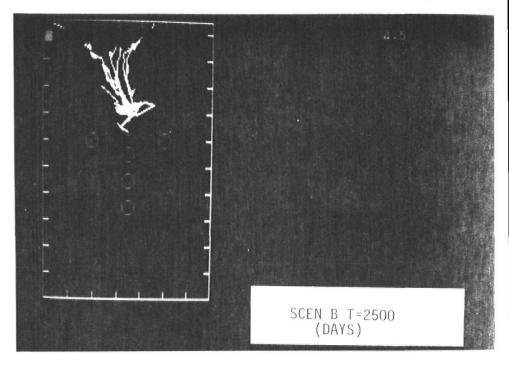
SCEN B T=100 (DAYS)











RANDOM-WALK NUMERICAL OUTPUT
SCENARIO A

```
///////BASIC TRANSPORT COEFFICIENTS\\\\\\\\
```

POROSITY = .2 LONGITUDINAL DISPERSIVITY = 50 TRANSVERSE DISPERSIVITY (FT) = 2 RETARDATION COEFFICIENT = 2 PARTICLE MASS (LBS) = 20

There are 7 sinks

Sink #	I coordinate	J coordinate	Withdrawal rate
1	4	13	266+0
2	6	13	26640
3	8	11	26640
4	8	13	266+0
5	8	15	26640
6	10	13	266+0
7	12	13	266+0

STARTING TIME OF SIMULATIN (DAYS) = 0

PRESENT SIMULATION TIME = 0 DAYS
INCREMENTAL SIMULATION TIME = .5 DAYS
40 FT

NP = 615
CONCENTRATION IN PUMPED WELL NUMBER 2 , IN PPM, IS = 359.976
CONCENTRATION IN PUMPED WELL NUMBER 3 , IN PPM, IS = 539.964
CONCENTRATION IN PUMPED WELL NUMBER 4 , IN PPM, IS = 1079.928
CONCENTRATION IN PUMPED WELL NUMBER 5 , IN PPM, IS = 179.988
CONCENTRATION IN PUMPED WELL NUMBER 6 , IN PPM, IS = 539.964

FOR THE RECORD -- THE MOVE WILL BE DONE OVER.

There are 0 sinks

Sink # I coordinate J coordinate Withdrawal rate

STARTING TIME OF SIMULATIN (DAYS) = 0

PRESENT SIMULATION TIME = 0 DAYS
INCREMENTAL SIMULATION TIME = .5 DAYS
DMAX = 40 FT

VF 30

FOR THE RECORD--THE MOVE WILL BE DONE OVER.

There are 7 sinks

```
Sink #
         I coordinate i coordinate withdrawal sate
          + 13
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          6
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                                 26640
3
          8
                      11
                                  26640
           8
                      13
                                  26640
          8
                      15
                                  266+0
          10
                     13
                                 26640
           12
                      13
                                 26640
```

STARTING TIME OF SIMULATIN (DAYS) = 0

ACCUMULATED TIME = 0 DAYS PARTICLES = 630
PARTICLE MAP

COORDINATES ARE IN FEET

5 22 | 3 5 9 9 20 | + 4 12 2 18 | + + 2 11 10 6 16 | + + 5 10 15 2 14 | + + 2 13 16 8 6 5 12 19 17 + + 7 25 23 10 | + 1 8 23 31 5 8 1 6 1 + 2 10 42 80 + 15 14 51 10 2 11 1 3 5 7 9 1 1 1 3 1

DO A SCREEN PRINT NOW OR PRESS (RETURN) TO GO BACK TO THE MENU.

PRESENT SIMULATION TIME = 0 DAYS
INCREMENTAL SIMULATION TIME = 100 DAYS
DMAX = 40 FT

NP = 361

CONCENTRATION IN PUMPED WELL NUMBER 1 , IN PPM, IS = 2.69982 CONCENTRATION IN PUMPED WELL NUMBER 2 , IN PPM, IS = 29.69802 CONCENTRATION IN PUMPED WELL NUMBER 3 , IN PPM, IS = 76.49493 CONCENTRATION IN PUMPED WELL NUMBER 4 , IN PPM, IS = 85.49433 CONCENTRATION IN PUMPED WELL NUMBER 5 , IN PPM, IS = 29.69802 CONCENTRATION IN PUMPED WELL NUMBER 6 , IN PPM, IS = 17.09886 CONCENTRATION IN PUMPED WELL NUMBER 7 , IN PPM, IS = .89994

ACC VLATED TIME = 100 DAYS PARTICLES = 361
PL LE MAP
COORDINATES ARE IN FEET

22 | + 2 6 8 6 3 + + 20 | + + 4 11 10 3 + + 18 | + + 2 6 2 4 + +

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                 12
              11
8
              6 22
           3
        2 10 26 33
            3
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                 4
                  3
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DO A SCREEN PRINT NOW OR PRESS (RETURN) TO GO BACK TO THE MENU.

PRESENT SIMULATION TIME = 100 DAYS INCREMENTAL SIMULATION TIME = .5 DAYS DMAX = 40 FT

NP = 361

FOR THE RECORD -- THE MOVE WILL BE DONE OVER.

PRESENT SIMULATION TIME = 100 DAYS INCREMENTAL SIMULATION TIME = 200 DAYS DMAX = 40 FT

NP = 137

CONCENTRATION IN PUMPED WELL NUMBER 1 , IN PPM, IS = 4.04973 TRATION IN PUMPED WELL NUMBER 2 , IN PPM, IS = 12.59916 TRATION IN PUMPED WELL NUMBER 3, IN PPM, IS = 24.29839 CONCENTRATION IN PUMPED WELL NUMBER 4 . IN PPM, IS = 42.2972 5 , IN PPM, IS = 8.5+9428CONCENTRATION IN PUMPED WELL NUMBER CONCENTRATION IN PUMPED WELL NUMBER 6 . IN PPM, IS = 8.099458 CONCENTRATION IN PUMPED WELL NUMBER 7 , IN PPM, IS = .8999+

ACCUMULATED TIME = 300 DAYS PARTICLES = 137 PARTICLE MAP

	*		COORI	DINA	TES	ARE	IN F	EET	
22	1	+	3	3	8	4	3	+	+
20	1	+	+	3	10	4	2	+	+
18	1	+	+	2	10	3	+	+	+
16	1	+	+	1	2	5	+	+	+
14	1	+	+	1	6	5	1	+	+
12	1	+	+	+	3	2	+	+	+
10	1	+	+	+	1	1	+	+	+
8	1	+	+	2	+	1	1	+	+
6	1	+	+	1	3	2	+	+	+
4	1	+	+	+	+	+	1	+	+
2	$\tau^{\mathbf{J}}$	+	+	+	1	+	+	+	+
	•								
			0	_	-	0			

1 3 5 7 1 1 1 3 5 PRESENT SIMULATION TIME = 300 DAYS INCREMENTAL SIMULATION TIME = .5 DAYS

)MAX = 40 FT

VP. 137

FOR THE RECORD -- THE MOVE WILL BE DONE OVER.

PRESENT SIMULATION TIME = 300 INCREMENTAL SIMULATION TIME = 500 DAYS DMAX = 40 FT

VP = 80CONCENTRATION IN PUMPED WELL NUMBER 1 , IN PPM, IS = .359976 CONCENTRATION IN PUMPED WELL NUMBER 2 . IN PPM, IS = .89994 CONCENTRATION IN PUMPED WELL NUMBER 3 . IN PPM, IS = .539964 CONCENTRATION IN PUMPED WELL NUMBER 4 , IN PPM, IS = 3.059796 CONCENTRATION IN PUMPED WELL NUMBER 5 . IN PPM, IS = 4.319711 CONCENTRATION IN PUMPED WELL NUMBER 6 . IN PPM. IS = 1.079928

ACCUMULATED TIME = 800 DAYS PARTICLES = 80 PARTICLE MAP

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1		+	+	+	4	2	1	+	+
16	1	+	+	1	2	+	+	+	+
14	1	+	+	+	+	+	+	+	+
12	1	+	+	+	+	+	+	+	+
10	1	+	+	+	+	+	+	+	+
8	1	+	+	+	+	+	+	+	+
6	1	+	+	+	+	+	+	+	+
4	1	+	+	+	+	+	+	+	+
2	1	+	+	+	+	+	+	+	+
		1	3	5	7	9	1	1	1 5

DO A SCREEN PRINT NOW OR PRESS (RETURN) TO GO BACK TO THE MENU.

PRESENT SIMULATION TIME = 800 INCREMENTAL SIMULATION TIME = .5 DAYS

DMAX = 40 FT

NP = 80

FO. THE RECORD--THE MOVE WILL BE DONE OVER.

PRESENT SIMULATION TIME = 800 DAYS INCREMENTAL SIMULATION TIME = 1700 DAYS

DMAX = 40 FT

COORDINATES ARE IN FEET

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16 | + + 1 + + +
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ACC JLATED TIME = 2500 DAYS PARTICLES = 61

DO A SCREEN PRINT NOW OR PRESS (RETURN) TO GO BACK TO THE MENU.

PRESENT SIMULATION TIME = 300 DAYS
INCREMENTAL SIMULATION TIME = .5 DAYS
DMAX = 40 FT

NP = 137

RANDOM-WALK NUMERICAL OUTPUT SCENARIO B

```
There are 0 sinks
```

S: I coordinate J coordinate Withdrawal rate

STARTING TIME OF SIMULATIN (DAYS) = 0

///////BASIC TRANSPORT COEFFICIENTS\\\\\\\\

POROSITY = .2 LONGITUDINAL DISPERSIVITY = 50 TRANSVERSE DISPERSIVITY (FT) = 2 RETARDATION COEFFICIENT = 2 PARTICLE MASS (LBS) = 20

There are 0 sinks

Sink # I coordinate J coordinate Withdrawal rate

STARTING TIME OF SIMULATIN (DAYS) = 0

ACCUMULATED TIME = 0 DAYS PARTICLES = 630

PARTICLE MAP

COORDINATES ARE IN FEET 3 5 9 5 22 1 4 12 9 20 1 2 18 | + + 2 11 10 6 16 | + + 5 10 15 2 + + 2 13 16 14 | + 2 7 19 17 12 6 10 | 7 25 23 1 8 23 31 5 8 2 10 42 80 7 - + 15 14 51 10 2 11 8 1 3 5 7 9 1 1 1 3 5 1

DC | CREEN PRINT NOW OR PRESS (RETURN) TO GO BACK TO THE MENU.

PRESENT SIMULATION TIME = 0 DAYS
INCREMENTAL SIMULATION TIME = .5 DAYS
DMAX = 40 FT

1.D - 830

OR THE RECORD -- THE MOVE WILL BE DONE OVER.

here are 7 sinks

i1.	I coordinate	J coordinate	Withdrawal rate
1	5	13	26640
2	8	8	26640
3	8	10	26640
4	8	12	26640
5	8	14	26640
6	8	16	26640
7	11	13	26640

STARTING TIME OF SIMULATIN (DAYS) = 0

PRESENT SIMULATION TIME = 0 DAYS INCREMENTAL SIMULATION TIME = 100 DAYS MAX = 40 FT

P = 295

ONCENTRATION IN PUMPED WELL NUMBER 1 , IN PPM, IS = 5.39964 'ONCENTRATION IN PUMPED WELL NUMBER 2 , IN PPM, IS = 69.2954 CONCENTRATION IN PUMPED WELL NUMBER 3 , IN PPM, IS = 80.99463 CONCENTRATION IN PUMPED WELL NUMBER 4, IN PPM, IS = 62.99582 CONCENTRATION IN PUMPED WELL NUMBER 5, IN PPM, IS = 54.89636 CONCENTRATION IN PUMPED WELL NUMBER 6, IN PPM, IS = 22.4985 "RATION IN PUMPED WELL NUMBER 7, IN PPM, IS = 5.39964

ACCUMULATED TIME = 100 DAYS PARTICLES = 295 PARTICLE MAP

COORDINATES ARE IN FEET 22 1 + 3 4 9 3 20 1 + + 5 12 10 + + 5 12 10 1 + 1 1 4 7 + + + + 2 6 9 4 + + + + 8 5 1 1 + + 3 10 7 4 + + + 2 12 13 1 + + + 5 5 6 2 + 18 1 16 | 14 | 12 | 10 | 8 + -4 9 13 32 + 3 3 5 3 1 3 5 7 9 1 1 1 3 5

DO A SCREEN PRINT NOW OR PRESS (RETURN) TO GO BACK TO THE MENU.

PRESENT SIMULATION TIME = 100 DAYS INCREMENTAL SIMULATION TIME = .5 DAYS DMAX = 40 FT

FOR THE RECORD--THE MOVE WILL BE DONE OVER.

PRESENT SIMULATION TIME = 100 DAYS
INCREMENTAL SIMULATION TIME = 200 DAYS
DMAX = 40 FT

VP = 119

CONCENTRATION IN PUMPED WELL NUMBER 1 . IN PPM, IS = 4.04973

CONCENTRATION IN PUMPED WELL NUMBER 2 . IN PPM, IS = 11.69922

CONCENTRATION IN PUMPED WELL NUMBER 3 . IN PPM, IS = 13.94907

CONCENTRATION IN PUMPED WELL NUMBER 4 . IN PPM, IS = 18.89874

CONCENTRATION IN PUMPED WELL NUMBER 5 . IN PPM, IS = 22.4985

CONCENTRATION IN PUMPED WELL NUMBER 6, IN PPM, IS = 6.299579 CONCENTRATION IN PUMPED WELL NUMBER 7, IN PPM, IS = 1.79988

ACCUMULATED TIME = 300 DAYS PARTICLES = 119
PARTICLE MAP

COORDINATES ARE IN FEFT

		,	LOORI	JINA	LES	ARE	IN F	EEI	
22 20	1	+ +	3 1	3 4	9 9	3 7	4 1	+	+
18 16	1	+	1	2 +	3 4	3	2	+	+
14 1	I	+	+	1 2	2	+	+	+ +	+
8	1	+	+	1 1	1	2	1	+	+
6	1	+	+	+	+	+	3	+	+
2	i	+	+	+	+	÷	+	+	+
		1	3	-5	7	9	1	1 3	1 5

DO A SCREEN PRINT NOW OR PRESS (RETURN) TO GO BACK TO THE MENU.

PRESENT SIMULATION TIME = 300 DAYS
INCREMENTAL SIMULATION TIME = .5 DAYS
DMAX = 40 FT

NP = 119

FOR THE RECORD -- THE MOVE WILL BE DONE OVER.

PRESENT SIMULATION TIME = 300 DAYS
INCREMENTAL SIMULATION TIME = 500 DAYS
DM. 40 FT

NP = 79

CONCENTRATION IN PUMPED WELL NUMBER 1 , IN PPM, IS = .719952

CONCENTRATION IN PUMPED WELL NUMBER 2 , IN PPM, IS = .179988

CONCENTRATION IN PUMPED WELL NUMBER 4 , IN PPM, IS = 1.259916

CCUMULATED TIME = 800 DAYS PARTICLES = 79 E MAP COORDINATES ARE IN FEET 22 | + 3 2 20 3 5 1 18 1 1 1 16 | 14 | 12 | 10 1 6 1 2 1 3 5 7 9 1 1 1 3 5

DO A SCREEN PRINT NOW OR PRESS (RETURN) TO GO BACK TO THE MENU.

PRESENT SIMULATION TIME = 800 DAYS
INCREMENTAL SIMULATION TIME = .5 DAYS
40 FT

VP = 79

DM

FOR THE RECORD--THE MOVE WILL BE DONE OVER.

PRESENT SIMULATION TIME = 800 DAYS
INCREMENTAL SIMULATION TIME = 1700 DAYS
DMAX = 40 FT

NP = 61
CONCENTRATION IN PUMPED WELL NUMBER 5 , IN PPM, IS = .1058753
CONCENTRATION IN PUMPED WELL NUMBER 6 , IN PPM, IS = .8470021

ACCUMULATED TIME = 2500 DAYS PARTICLES = 61 PARTICLE MAP

COORDINATES ARE IN FEET

	_								
22	1	+	3	2	7	3	2	+	+
20	1	+	+	+	1	+	+	+	+
1		+	+	1	1	+	+	+	+
1		+	+	+	+	+	+	+	+
14	i	+	+	+	+	+	+	+	+
12	ı	+	+	+	+	+	+	+	+
10	1	+	+	+	+	+	+	+	+
8	1	+	+	+	+	+	+	+	+
6	1	+	+	+	+	+	+	+	+
	2.					į,		1	-1

1 3 5 7 9 1 1 1 1 3 5

DO A SCREEN PRINT NOW OR PRESS (RETURN) TO GO BACK TO THE MENU.

PRESENT SIMULATION TIME = 2500 DAYS INCREMENTAL SIMULATION TIME = .5 DAYS

DMAX = 40 FT

VP = 61

FOR THE RECORD -- THE MOVE WILL BE DONE OVER.

RANDOM-WALK NUMERICAL OUTPUT
SCENARIO C

////////BASIC TRANSPORT COEFFICIENTS\\\\\\\\

POROSITY = .2 LONGITUDINAL DISPERSIVITY = 50 TRANSVERSE DISPERSIVITY (FT) = 2 RETARDATION COEFFICIENT = 2 PARTICLE MASS (LBS) = 20

There are 0 sinks

Sink # I coordinate J coordinate Withdrawal rate

STARTING TIME OF SIMULATIN (DAYS) = 0

ACCUMULATED TIME = 0 DAYS PARTICLES = 630 PARTICLE MAP

COORDINATES ARE IN FEET

2 1 + 3 5 9 5 3 + +

→ 12 9 20 + 2 11 10 10 1.5 1 + + 2 13 16 19 17 7 25 23 10 5 23 8 31 42 80 6 2 10 7 1.5 1 + 51 10 2 11 8

> 1 3 5 7 9 1 1 1 1 3 5

DO A SCREEN PRINT NOW OR PRESS (RETURN) TO GO BACK TO THE MENU.

PRESENT SIMULATION TIME = 0 DAYS
INCREMENTAL SIMULATION TIME = .5 DAYS
DMAX = +0 FT

VP 630

FOR THE RECORD -- THE MOVE WILL BE DONE OVER.

There are 7 sinks

STARTING TIME OF SIMULATIN (DAYS) = 0

PRESENT SIMULATION TIME = 0 DAYS
INCREMENTAL SIMULATION TIME = 100 DAYS
DMAX = 40 FT

NP = 432

CONCENTRATION IN PUMPED WELL NUMBER 1 . IN PPM, IS = 16.19892

CONCENTRATION IN PUMPED WELL NUMBER 2 . IN PPM, IS = 29.69802

CONCENTRATION IN PUMPED WELL NUMBER 3 . IN PPM, IS = 31.4979

CONCENTRATION IN PUMPED WELL NUMBER 4 . IN PPM, IS = 17.9988

CONCENTRATION IN PUMPED WELL NUMBER 5 . IN PPM, IS = 39.59737

CONCENTRATION IN PUMPED WELL NUMBER 6 . IN PPM, IS = 33.29778

CONCENTRATION IN PUMPED WELL NUMBER 7 . IN PPM, IS = 9.899339

ACCUMULATED TIME = 100 DAYS PARTICLES = 432
PARTICLE MAP

COORDINATES ARE IN FEET 5 8 2.0 + 2 18 1 1 5 22 25 + + 1 5 1 + 1 3 5 7 9

DO A SCREEN PRINT NOW OR PRESS (RETURN) TO GO BACK TO THE MENU.

PRESENT SIMULATION TIME = 100 DAYS
INCREMENTAL SIMULATION TIME = .5 DAYS
DMAX = 40 FT

N +32

FOR THE RECORD -- THE MOVE WILL BE DONE OVER.

PRESENT SIMULATION TIME = 100 DAYS

```
P = 166
CONCENTRATION IN PUMPED WELL NUMBER 1, IN PPM, IS = 6.299579
ONCENTRATION IN PUMPED WELL NUMBER 2, IN PPM, IS = 18.89874
   NTRATION IN PUMPED WELL NUMBER 3 , IN PPM, IS = 29.24806
     TRATION IN PUMPED WELL NUMBER 4 , IN PPM, IS = 8.549428
CONCENTRATION IN PUMPED WELL NUMBER 5 , IN PPM, IS = 35.99761 CONCENTRATION IN PUMPED WELL NUMBER 6 , IN PPM, IS = 17.9988
CONCENTRATION IN PUMPED WELL NUMBER 7 . IN PPM, IS = 2.69982
```

ACCUMULATED TIME = 300 DAYS PARTICLES = 166 PARTICLE MAP

COODDINATES ADE IN EFFT

		(COOR	DINA	TES	ARE	IN F	$-F\Gamma$	
	-					-			
22	1	+	4	2	9	6	3	+	+
20	1	+	+	5	9	3	+	+	+
18	1	+	+	+	3	1	+	+	+
16	1	+	+	+	10	12	+	+	+
14	1	+	+	6	7	10	3	+	+
12	1	+	1	4	9	8	+	+	+
10	1	+	1	+	2	2	+	+	+
8	1	+	+	+	+	1	1	+	+
6	1	+	+	+	2	+	1	+	+
4	1	+	+	+	+	+.	+	+	+
2	1	+	+	+	+	+	+	+	+
		1	3	5	7	9	1	1	1
							1	3	5

DO A SCREEN PRINT NOW OR PRESS (RETURN) TO GO BACK TO THE MENU.

PRESENT SIMULATION TIME = 300 DAYS INCREMENTAL SIMULATION TIME = .5 DAYS DMAX = 40 FT

NP = 166

FOR THE RECORD -- THE MOVE WILL BE DONE OVER.

PRESENT SIMULATION TIME = 300 DAYS INCREMENTAL SIMULATION TIME = 500 DAYS DMAX = 40 FT

NP = 76CONCENTRATION IN PUMPED WELL NUMBER 1 , IN PPM, IS = .359976 CONCENTRATION IN PUMPED WELL NUMBER 2, IN PPM, IS = 1.439904 CONCENTRATION IN PUMPED WELL NUMBER 3 . IN PPM, IS = 5.399639 CO NTRATION IN PUMPED WELL NUMBER + , IN PPM, IS = 3.059796 ATRATION IN PUMPED WELL NUMBER 5 . IN PPM, IS = 4.679687 CL CONCENTRATION IN PUMPED WELL NUMBER 6 . IN PPM. IS = 1.259916

			COORDINATES		ARE	IN F	EET		
	-				- - -				
22	ı	+	3	2	8	4	2	+	+
20	1	+	1	3	8	+	+	+	+
1	1	+	+	+	3	+	+	+	+
		+	+	+	+	1	+	+	+
1 -	1	+	+	+	+	+	+	+	+
12	1	+	+	+	+	+	+	+	+
10	1	+	+	+	+	+	+	+	+
8	1	+	+	+	+	+	+	+	+
6	1	+	+	+	+	+	+	+	+
4	1	+	+	+	+	+	+	+	+
2	1	+	+	+	+	+	+	+	+
	-								
		1	3	5	7	9	1	1	1
							1	3	5

DO A SCREEN PRINT NOW OR PRESS (RETURN) TO GO BACK TO THE MENU.

PRESENT SIMULATION TIME = 800 DAYS
INCREMENTAL SIMULATION TIME = .5 DAYS
DMAX = 40 FT

NP = 76

FOR THE RECORD -- THE MOVE WILL BE DONE OVER.

PRESENT SIMULATION TIME = 800 DAYS
INCREMENTAL SIMULATION TIME = 1700 DAYS
DMAX = 40 FT

NP = 60

CONCENTRATION IN PUMPED WELL NUMBER 3 . IN PFM, IS = 5.293764E-02 CONCENTRATION IN PUMPED WELL NUMBER 4 . IN PPM, IS = .7940645

ACCUMULATED TIME = 2500 DAYS PARTICLES = 60 PARTICLE MAP

1 3 5 7 9 1 1 1 1 1 5

DO A SCREEN PRINT NOW OR PRESS (RETURN) TO GO BACK TO THE MENU. 0211781

PRESENT SIMULATION TIME = 2500 DAYS INCREMENTAL SIMULATION TIME = .5 DAYS = 40 FT

VP 60

FOR THE RECORD -- THE MOVE WILL BE DONE OVER.

RANDOM-WALK NUMERICAL OUTPUT

SCENARIO D

```
There are 0 sinks
```

S I coordinate J coordinate Withdrawal rate

STARTING TIME OF SIMULATIN (DAYS) = 0

///////BASIC TRANSPORT COEFFICIENTS\\\\\\\\

POROSITY = .2 LONGITUDINAL DISPERSIVITY = 50 TRANSVERSE DISPERSIVITY (FT) = 2 RETARDATION COEFFICIENT = 2 PARTICLE MASS (LBS) = 20

ACCUMULATED TIME = 0 DAYS PARTICLES = 630 PARTICLE MAP

COORDINATES ARE IN EFFT

		(LOOR	DINA	IES	AKE	TX FF	t. 1	
	-								
22	1	+	3	5	9	5	3	+	+
20	1	+	+	4	12	9	2	+	+
	- 1	+	+	2	11	10	6	+	+
1	1	+	+	5	10	15	2	+	+
14	1	+	+	2	13	16	8	+	+
12	1	+	2	7	19	17	6	+	+
10	1	+	+	7	25	23	5	+	+
8	T	+	1	8	23	31	5	+	+
6	1	+	2	10	+2	80	7	1	+
4	1	+	+	15	14	51	10	+	+
2	1	+	1	4	2	1 1	8	+	+
		1	3	5	7	9	1	1	1
							1	3	5

DO A SCREEN PRINT NOW OR PRESS (RETURN) TO GO BACK TO THE MENU.

PRESENT SIMULATION TIME = 0 DAYS
INCREMENTAL SIMULATION TIME = .5 DAYS
DMAX = 40 FT

NP = 630

F IE RECORD -- THE MOVE WILL BE DONE OVER.

There are 9 sinks

Sink # I coordinate J coordinate Withdrawal rate 1 4 9 21600 2 1600

```
5 7 3 + vj
5
                 8
                                   17
                                                     266+0
                 9
                                  15
                                                     265+0
                                  13
                 10
                 11
                                  1 1
                                                     21600
                 12
                                                     21600
```

STARTING TIME OF SIMULATIN (DAYS) = 0

PRESENT SIMULATION TIME = 0 DAYS INCREMENTAL SIMULATION TIME = 100 DAYS DMAX = 40 FT

VP = 378CONCENTRATION IN PUMPED WELL NUMBER 1, IN PPM, IS = 13.31911 CONCENTRATION IN PUMPED WELL NUMBER 2 , IN PPM, IS = 18.86874 CONCENTRATION IN PUMPED WELL NUMBER 3 , IN PPM, IS = 49.49671 CONCENTRATION IN PUMPED WELL NUMBER 4 . IN PPM, IS = 42.29719 CONCENTRATION IN PUMPED WELL NUMBER 5 , IN PPM, IS = 9.899339CONCENTRATION IN PUMPED WELL NUMBER 6, IN PPM, IS = 39.59737 CONCENTRATION IN PUMPED WELL NUMBER 7 , IN PPM, IS = 52.19653 CONCENTRATION IN PUMPED WELL NUMBER 8 . IN PPM. IS = 7.769 + 81CONCENTRATION IN PUMPED WELL NUMBER 9 , IN PPM, IS = 1.109926

ACCUMULATED TIME = 100 DAYS PARTICLES = 378 PAPTICLE MAP

COORDINATES ARE IN FEET

		(COOR	PKID	162	AKE	IN FE	ELI	
	-								
22	1	+	3	2	10	7	3	+	+
20	1	+	1	4	9	8	1	+	+
18	1	+	+	1	3	6	+	+	+
16	1	+	+	3	6	14	+	+	+
14	1	+	+	1	15	19	1	+	+
12	1	+	2	3	22	23	4	+	+
10	1	+	+	3	13	19	3	+	+
8	1	+	1	1	16	25	3	+	+
6	1	+	3	1 1	1 +	2 4	6	+	+
4	t	+	1	2	6	8	5	+	+
2	1	+	+	+	1	+	1	+	+
	-								
		1	3	5	7	9	1	1	1
							1	3	5
		-							

DO A SCREEN PRINT NOW OR PRESS (RETURN) TO GO BACK TO THE MENU.

PRESENT SIMULATION TIME = 100 DAYS INCREMENTAL SIMULATION TIME = .5 DAYS = 40 FT DM

NP - 378

FOR THE RECORD -- THE MOVE WILL BE DONE OVER.

```
NP = 116

CONCENTRATION IN PUMPED WELL NUMBER 1 , IN PPM, IS = 3.329778

CONCENTRATION IN PUMPED WELL NUMBER 2 , IN PPM, IS = 8.324445

CONCENTRATION IN PUMPED WELL NUMBER 3 , IN PPM, IS = 21.59856

CONCENTRATION IN PUMPED WELL NUMBER 4 , IN PPM, IS = 23.84842

CONCENTRATION IN PUMPED WELL NUMBER 5 , IN PPM, IS = 5.399639

CONCENTRATION IN PUMPED WELL NUMBER 6 . IN PPM, IS = 31.49791

CONCENTRATION IN PUMPED WELL NUMBER 7 , IN PPM, IS = 31.49791

CONCENTRATION IN PUMPED WELL NUMBER 8 . IN PPM, IS = 6.104593

CONCENTRATION IN PUMPED WELL NUMBER 9 , IN PPM, IS = .5549629
```

ACCUMULATED TIME = 300 DAYS PARTICLES = 116
PARTICLE MAP

COORDINATES ARE IN FEET

22 | + 3 | 2 | 8 | 3 | 2 | + +

22	1	+	3	2	8	3	2	+	+
20	1	+	1	1	5	7	+	+	+
18	1	+	+	2	5	3	+	+	+
16	1	+	+	1	.3	2	+	+	+
14	1	+	+	+	9	5	2	+	+
12	1	+	1	2	3	1	2	+	+
10	1	+	+	+	+	1	+	+	+
8	1	+	+	+	+	+	+	+	+
6	1	+	+	+	+	1	+	+	+
4	1	+	+	+	+	+	+	+	+
	1	+	+	+	+	+	+	+	+
	-								
		1	3	5	7	9	1	1	1
							1	3	5

DO A SCREEN PRINT NOW OR PRESS (RETURN) TO GO BACK TO THE MENU.

PRESENT SIMULATION TIME = 300 DAYS
INCREMENTAL SIMULATION TIME = .5 DAYS
DMAX = 40 FT

NP = 116

FOR THE RECORD -- THE MOVE WILL BE DONE OVER.

PRESENT SIMULATION TIME = 300 DAYS
INCREMENTAL SIMULATION TIME = 500 DAYS
DMAX = 40 FT

NP = 66

COT INTRATION IN PUMPED WELL NUMBER 2 . IN PPM, IS = .2219852

COLLENTRATION IN PUMPED WELL NUMBER 3 . IN PPM, IS = .719952

COLLENTRATION IN PUMPED WELL NUMBER 4 , IN PPM, IS = 3.059796

CONCENTRATION IN PUMPED WELL NUMBER 5 , IN PPM, IS = 1.79988

CONCENTRATION IN PUMPED WELL NUMBER 6 , IN PPM, IS = 2.69982

CONCENTRATION IN PUMPED WELL NUMBER 7 , IN PPM, IS = .359976

CONCENTRATION IN PUMPED WELL NUMBER 8 , IN PPM, IS = .2219852

PARTICLE MAP

COORDINATES ARE IN FEET

		(LOORI	JINA	IES	ARE	IN FI	EEI	
	-								
4	1	+	3	2	8	4	2	+	+
20	1	+	1	+	2	+	+	+	+
18	1	+	+	1	1	+	+	+	+
16	1	+	+	+	1	+	+	+	+
14	1	+	+	+	+	+	+	+	+
12	1	+	+	+	+	+	+	+	+
10	1	+	+	+	+	+	+	+	+
8	1	+	+	+	+	+	+	+	+
6	1	+	+	+	+	+	+	+	+
4	1	+	+	+	+	+	+	+	+
2	1	+	+	+	+	+	+	+	+
	_								
		1	3	5	7	9	1	1	1
		-				*	1	3	5
							•	9	-

DO A SCREEN PRINT NOW OR PRESS (RETURN) TO GO BACK TO THE MENU.

PRESENT SIMULATION TIME = 800 DAYS INCREMENTAL SIMULATION TIME = .5 DAYS DMAX = 40 FT

NP = 66

FOR THE RECORD -- THE MOVE WILL BE DONE OVER.

PRESENT SIMULATION TIME = 800 DAYS INCREMENTAL SIMULATION TIME = 1700 DAYS DMAX = 40 FT

NP = 60

CONCENTRATION IN PUMPED WELL NUMBER 4, IN PPM, IS = .1058753 CONCENTRATION IN PUMPED WELL NUMBER 5 , IN PPM, IS = 5.293764E-02 CONCENTRATION IN PUMPED WELL NUMBER 6, IN PPM, IS = .1588129

ACCUMULATED TIME = 2500 DAYS PARTICLES = 60 PARTICLE MAP

		(COORI	DINAT	res s	ARE	IN F	EET	
	-								
22	1	+	3	2	8	4	2	+	+
20	1	+	+	+	+	+	+	+	+
18	1	+	+	+	+	+	+	+	+
15	1	+	+	+	+	+	+	+	+
	4	+	+	+	+	+	+	+	+
1 -		+	+	+	+	+	+	+	+
10	1	+	+	+	+	+	+	+	+
8	1	+	+	+	+	+	+	+	+
6	1	+	+	+	+	+	+	+	+
4	ı	+	+	+	+	+	+	+	+
2	1	+	+	+	+	+	+	+	+

1 3 5 7 ° 1 1 1 1 1 1 5

D SCREEN PRINT, NOW OR PRESS (RETURN) TO GO BACK TO THE MENU.

PRESENT SIMULATION TIME = 2500 DAYS
INCREMENTAL SIMULATION TIME = .5 DAYS
DMAX = 40 FT

NP = 60

FOR THE RECORD -- THE MOVE WILL BE DONE OVER.

TITLE .	COMPREHENSIDE	RIFS STUDY -A	SARCO, INC.	EAST
	NA, MONTANA			
FILE NO	o. <u>1070000</u>	DOCUMENT NO	93.11682	021/188
		SDMS		• .

TITLEC	OMPREHENSIVE	RIFS STUD	DY - ASARCO, INC. EAST
	MONTANA		
FILE NO.	1070000	DOCUMENT NO	· <u>0211602</u> 0211789
		•	MS 1/20/38

TITLE COUPEE	HENSIVE RIPS	STUDY - ASA	RCO INC. E	A57
HELENA M	ONTANA		•	
FILE NO	<i>70000</i> DC	CUMENT NO	001/02	
•			0211740-02117	192
			SDM 5 11-	20128

TITLE COMPREHENSION	RIFS STUDY - ASARCO, INC. EAST
HELENA MONTANA	
in the second	
FILE NO. 1070000	DOCUMENT NO. 6211793
	SDMS 1120138

TITLE CO	MPREHEIRSIDE I	RI /FS STUDY - ASARCO, INC. EAST	
	MONTANA		
FILE NO.	1070000	DOCUMENT NO. 6211794 SDMS 1120 138	

TITLE _Co	MPREHENSIVE	RIFS	STUDY -	ASARCO,	INC. EA.	ST
	MONTANA				-	
FILE NO	1070000	_ DOCUME	NT NO.	0211799	5	
			5DM S	5 1120	138	

TITLE CON	APREHEDSIVE	RIJES	STUDY - ASARCO, INC. EAST	
	MONTANA			
FILE NO	1070000	DOCUME	ENT NO. <u>0 all 796</u> SDMS 1120138	

TITLE	COM	PREHENSIOE	RILFS STUDY	- ASARCO, INC	. EAST
HELL	=NA	MONTANA			
FILE NO).	1070000	DOCUMENT NO.	6211797	
				1120138	

TITLE C	OMPREHENSIVE	RILFS STUP	Y - ASARCO, INC.	EAST
	A MONTANA			
FILE NO.	1070000	DOCUMENT NO.	0211718	
			SOMS 1/2	0138

TITLE Co.	MPREHENSIVE	RIJES STUDY-ASARCO, INC. EAST	
	MONTANA		
FILE NO	1070000	DOCUMENT NO. 211 799	
		SDMS 1120138	

TITLE _C	OMPREHENSIDE	RIFS STUDY - ASARCO, INC. EAST	•
	A, MONTANA		
FILE NO.	1070000	DOCUMENT NO	_
		5pms 1120138	

TITLE <u>Co</u>	OMPREHENSIVE I	RIJES STUDY	· ASARCO INC. EAST	<u> </u>
	MONTANA			
FILE NO.	1010000	DOCUMENT NO.	02(1801	
_			15 1120138	